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Road Research Technical Paper No. 46

The London-Birmingham Motorway

TRAFFIC AND ECONOMICS

Part I. Traffic Investigation

by

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Part II. Economic Assessment

by

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FOREWORD

MOTORWAYS are one of the most important and controversial means of meeting the special needs of modern motor traffic which, for the most part, has to use a system of roads inherited from the age of the horse and cart—if not before. They have great advantages to traffic but are expensive as pieces of construction. Expenditure on new roads and bridges is a matter of record; but nothing as comprehensive as the present study of a large-scale project has yet been done, in a British setting, to identify prospective users, to value their gains (and any losses that may be feared) and to bring these together in the one account with outlays on construction and all other costs. This report describes an attempt to make such an assessment of the traffic on the motorway between London and Birmingham.

The study was not undertaken with a view to deciding whether or not the London–Birmingham motorway should be selected as a profitable scheme, but it was undertaken as a subject of research to see whether reliable methods of assessing both the traffic that would flow upon it and the economic value of the scheme, could be devised. This particular motorway was chosen because it seemed likely to be the first substantial work to be undertaken, the line was known, and it was conveniently situated in relation to both the Road Research Laboratory and the University of Birmingham.

In this study, observations were made of traffic on existing roads and predictions were made of the amounts of traffic expected on the motorway. Gains and losses to this traffic and to that remaining on the existing roads have been estimated and allowances made for reduction in accidents. The foreseeable economic return upon the outlay to be incurred has also been assessed. When everything has been done and costs and returns all taken into account, in so far as they can be identified and valued, the investment of public funds in the motorway is shown to be profitable although a full comparison with other possible investments could not be made.

While this study was going on, construction of the motorway was started. Observations of traffic made before the motorway is opened can thus be compared with observations taken after it has been in use. The methods employed can be checked, and the accuracy of the predictions verified. This is the more necessary since the motorway is the first of its kind in Great Britain and data about traffic had in part to be gauged from the experience, different as this undoubtedly is, of other countries—the United States of America, the Netherlands and Germany, France and Belgium—all of which have had motorways for some time.

Expenditure on the enquiries described herein can be put at about £20 000. The capital cost of the motorway, however, is estimated to be about £24 000 000. About one-tenth of 1 per cent has thus been

spent on enquiries designed to estimate the gains accruing from the investment. A sum of £60 000 000 is now to be invested annually in the construction and reconstruction of the roads of Great Britain.

The work has been done jointly by the University of Birmingham and the Road Research Laboratory of the Department of Scientific and Industrial Research. The investigations by the Road Research Laboratory were carried out as part of the research programme of the Road Research Board and were financed directly by the Laboratory. Some of the field work supervised by the Road Research Laboratory and the contribution of the University of Birmingham were paid for partly by funds supplied by the Ministry of Transport and Civil Aviation and partly by assistance received under the Conditional Aid Scheme for the use of counterpart funds derived from United States Economic Aid, for which acknowledgement is made. Neither of these sponsors accepts responsibility for the views expressed nor is bound by the results of the study.

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PART I. TRAFFIC INVESTIGATION

INTRODUCTION

THE main function of the traffic investigation now to be described was to provide estimates of the amount of traffic likely to transfer to the London–Birmingham motorway and of the consequent savings in vehicle time. The basic data used in producing these estimates were obtained in 1955 by carrying out a survey of the origins and destinations of traffic and by measuring journey times on the existing road network. In the origin-and-destination survey, traffic was intercepted at 23 points on roads in the area likely to be affected and 41 000 drivers were interviewed about their journeys. The journey-time measurements, which covered 1800 miles of road, were obtained by means of a test vehicle. These data were analysed in conjunction with assumptions about speeds on the motorway which were subsequently checked against speed measurements, made specially for this purpose, on motorways in four European countries. This part of the paper describes the methods used in collecting and analysing the traffic data and presents the results obtained; it also gives estimates of the reductions in the numbers of accidents.

The London–Birmingham motorway comprises several motorway schemes usually described as follows: St. Albans By-pass (17 miles), London–Yorkshire motorway First Section (53 miles), Dunchurch By-pass (1¾ miles), Crick spur (part of London–Yorkshire motorway Second Section—1¾ miles). Details of the motorway are given in the map in Fig. 1: the main portion, which runs from Aldenham, on the Watford By-pass (A.41), to west of Dunchurch near Rugby on A.45, is 68 miles long, and the total length, including the three spurs, is about 74 miles. Apart from the end points, access from other roads is limited to nine points along the motorway (Fig. 2). When the traffic analyses were carried out, proposals made by the Ministry of Transport and Civil Aviation did not include the Dunchurch By-pass and the Crick spur (Fig. 1): it was not possible, therefore, to allow for these additions in the main part of the investigation. Separate calculations have suggested, however, that, although these additions would alter some of the details of the traffic analysis, the effect on the main features of the traffic estimates and the economic assessment would be negligible.

ORIGIN-AND-DESTINATION SURVEY

Information about the origins and destinations of traffic on roads in the area likely to be affected was obtained by intercepting vehicles at the 23 points shown in Fig. 3 and inviting a sample of drivers to provide the necessary information, which was noted on a questionnaire. Traffic in one direction only was sampled on a given day.

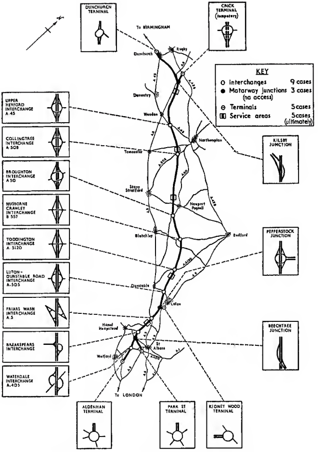


FIG. 2. Access points on the London–Birmingham motorway

Field procedure

Wherever possible a lay-by was used for interviewing but, where no suitable lay-by was available, the nearside lane of a three-lane carriageway or one of the lanes of a dual carriageway was separated off by means of barriers. A typical layout of a survey station is shown in Fig. 4. Temporary traffic signs in advance of the station asked drivers to proceed slowly and to stop if requested. Particular attention was given to the design and siting of the signs because it was essential in the interests of safety, as well as to facilitate the sampling technique, that the approaching traffic should be travelling more slowly than usual and that there should be no overtaking. Lettering, 8 inches high, was used and signs were placed on the offside verge as well as on the nearside verge, as shown in Fig. 5. As a further precaution, barriers were used in many instances to funnel traffic into a single line as it approached the survey station.

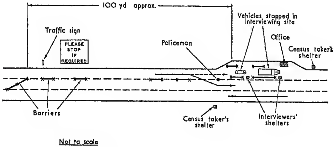


FIG. 4. Typical layout of O.D. survey station

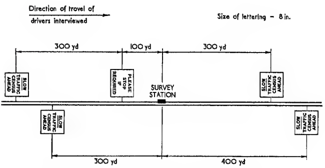


FIG. 5. Siting of traffic signs at O.D. survey station

Sampling technique

The usual practice in origin-and-destination surveys is to interview all drivers or a constant proportion of drivers. Unless accurate information is available about the traffic flow to be expected and the time required for each interview, this method may lead to the formation of queues of vehicles and it may cause the interviewers to be overworked, with consequent loss of accuracy. These undesirable features may be avoided by resorting to the uneconomical procedure of engaging enough interviewers to meet all eventualities.

In this investigation a new sampling technique was devised to satisfy the following requirements:

(i) vehicle delay should be kept to a minimum;

(ii) drivers interviewed should be a random sample of all drivers in the particular direction;

(iii) the two interviewers should be working continuously but should not be overworked.

No attempt was made to keep the proportion of drivers interviewed constant. The proportion varied according to the amount of traffic and the rate at which the interviewers worked. The technique used was as follows:

While interviewing was going on, the rest of the traffic was allowed to proceed past the site without hindrance. Shortly before the completion of each interview, a policeman entered the carriageway on the approach side of the interviewing site. His presence caused vehicles to reduce speed and he allowed them to pass the interviewing site in a single line. When the previous vehicles had left the interviewing site and the interviewers were ready to start fresh interviews, a signal was given to the policeman by the supervisor or by one of the interviewers. The policeman then directed the first two vehicles that reached him into the interviewing site, and he allowed the rest of the traffic to carry on; he then usually left the carriageway until the interviews were almost complete and the procedure was repeated. On occasions, however, conditions were such that he considered it advisable to remain in the carriageway throughout.

Strict adherence to this technique was necessary to ensure that the above requirements were satisfied. For example, on some occasions it was found that the policeman was not waiting for a signal before drawing the two vehicles out of the traffic stream; this was often prompted by the failure of the supervisor or interviewer to give the signal on previous occasions. The usual consequence was that the interviewers were overworked and that the forms were not properly completed. Alternatively, it meant that vehicles had to wait until the interviewers were ready. The most serious objection to this departure from the prescribed technique was that it empowered the policeman to select the vehicles for interview, thus violating the requirement of a random sample.

Another fault, which occurred on a few occasions, was that at the time the signal was expected vehicles were being permitted to pass the site at too great a speed. This meant that the policeman was unable to direct to the interviewing site the first two vehicles that reached him after receiving the signal. Instead, he allowed the faster vehicles to pass before making his selection and the sample was biassed in favour of slow-moving commercial vehicles. Most of the error arising from this fault was removed in the analysis by introducing the complication of using separate sampling factors for the different classes of vehicle.

Although requirements (ii) and (iii) were sometimes not fulfilled because of departures from the recommended sampling technique, requirement (i) was

normally satisfied. The vehicles required for interview were not forced to queue up beforehand while the delay to other vehicles was almost negligible. The form of questioning was rather more elaborate than usual, mainly because additional information was required in the investigation of the economic value of the motorway forming Part II of this paper: therefore, interviewing in general lasted about 50 or 60 seconds. Although this may seem excessive, the interviewers reported that this delay did not seem to irritate drivers and that very good co-operation was obtained. The experience gained in this investigation stresses the importance of distinguishing between delay caused by queueing and the time spent in interviewing.

Location of survey stations

The positions of the 23 survey stations are listed in Appendix 1 and they are shown on the map in Fig. 3. The points were highly concentrated on road A.5 and on other roads near the line of the proposed motorway, so as to intercept short-distance as well as long-distance traffic which might use the motorway. On the outlying roads the stations were infrequent since only long-distance traffic on these roads need be considered as potential motorway traffic. This method of arranging the interception points is a departure from the usual method of locating the points on a number of screen lines drawn at right angles to the direction of travel. The 'screen-line' method produces the same concentration of interception points on the different routes irrespective of their importance, but has the advantage of being simple to analyse. The method used in this investigation allocates the points roughly in proportion to the estimated importance of the various routes but requires a special method of analysis (see p. 16).

Duration of survey

At each station, the survey lasted for 16 hours (6 a.m. to 10 p.m.) on each of two weekdays, one day for interviewing in each direction. With station 11 on A.1 in Hertfordshire and station 31 on A.34 in Oxfordshire an extra two days' work was carried out to improve the reliability of the information about long-distance traffic on these routes. Because of the high flow of commercial traffic at night on A.5 and A.1, interviewing was carried out on two nights from 10 p.m. to 6 a.m. at stations 56 and 11. This required the erection of special flood-lighting equipment powered by mobile generators. Four 500-W lamps were suspended across the road, at a height of 20 ft, from poles mounted in the verges, and two flood-lights were mounted to shine across the road to assist the interviewers. The traffic signs were also illuminated.

The schedule of work, given in Appendix 2, was arranged so that each county authority had to work at only one site on a given day. Another requirement was that no vehicle would be stopped more than once on a single journey; vehicles making return trips and regular users of the roads were, of course, liable to be stopped more than once on different occasions.

The survey was limited to weekdays but in the analysis allowance was made for Saturday and Sunday traffic by using factors derived from traffic-census data. It would not have been possible, with the resources available, to investigate weekend journeys with the same degree of accuracy as could be done for weekday journeys because of the wide fluctuations, due to season and weather, in the amounts and character of weekend traffic.

Information obtained in interviews

Two types of form were used by interviewers to record the details given by drivers, one for private cars and coaches, and the other for goods vehicles; these are reproduced in Appendices 3 and 4 respectively. Before the interview was begun the interviewer formally obtained the assent of the driver to co-operate and told him briefly the purpose of the survey; the recommended form of the preamble is given in section (D) on the form.

The relevant place-names were entered in Sections (E) and (F) as follows:

Section (E) (i) origin of journey
(ii) last 'essential stop' (if any)

Section (F) (i) destination of journey
(ii) next 'essential stop' (if any)

The term 'essential stop' is used here to denote a stop at a place for a purpose that could be realized only at that particular place. It was considered to be very important to obtain this information since many drivers are not concerned merely with travelling from one place to another; businessmen, for example, sometimes combine several business calls on a single trip and goods vehicles often stop to make collections or deliveries *en route*. In assessing the amount of travel between different centres it was considered that a journey segmented by a number of 'essential stops' should be regarded, not as a single journey, but as a number of separate journeys. Hence, in interpreting the record of interview of a driver who had made one or more 'essential stops' before being interviewed, the place of the last 'essential stop' in part (ii) of section (E) is treated as the origin of the journey and the entry in part (i) is ignored. Likewise, the place of the next 'essential stop' proposed, if any, in part (ii) of section (F) is treated as the destination of the journey instead of the entry in part (i). It is not necessary to put the information about the other segments of the journey on record; if these segments have a bearing on the investigation then the driver would be liable to be stopped for interview at other stations and the information about the other segments obtained independently. The term 'essential stop' does not, of course, refer to incidental stops for the purpose of obtaining petrol, meals, refreshments, toilet facilities, etc., since such stops do not contribute to a driver's purpose in travelling and the purpose in stopping could be realized at a variety of points *en route;* when the motorway is constructed, such stops would be transferred to points on the motorway.

The term 'essential stop' is used only for convenience in describing the concept and it was not used in questioning drivers. As shown in Appendices 3 and 4, the style of questioning varied with the class of vehicle, and interviewers were given instructions on the method of dealing with cases in which the prescribed form of questions did not seem applicable. With multi-axled goods vehicles, only one question was asked in section (E), and one in section (F). It referred to the load rather than to the driver because it is known to be common practice for the driver of a long-distance heavy goods vehicle to be changed *en route* but for the load and the vehicle to carry on. The use of the impersonal form of question avoids underestimation of the length of journey.

The six squares at the bottom of section (E) were used in the office to enter the national grid reference of the place-name, As explained above, if there was an entry in part (ii), this was used instead of the entry in part (i). The six squares at the bottom of section (F) were used in a similar way.

The category of journey of private cars in section (G) was obtained by showing the driver a card bearing the following inscription:

Please state the number of the category into which your journey falls

1	Travelling for private reasons
2	Expenses of this vehicle on this journey paid by my employer or by my own business concern (wholly or partly)
3	Travelling on business. Expenses of this vehicle on this journey paid by myself
4	Travelling to or from my place of work at my own expense
5	Not included in any of the above

This information is required in assessing the economic value of the savings in running costs and in the time of occupants of vehicles transferring to the motorway. Since the details required are of a personal nature, interviewers were instructed to ask only for the number of the category of journey and not to discuss the subject with the driver.

The information about occupancy in section (G) was obtained by inspection.

Sections (J), (K), (L), (M) and (N) were used to provide special information at a few of the stations. Section (J) was completed in two cases in which traffic from the London area had the choice of two important routes before arriving at the station; the answer was obtained by displaying a card bearing two lists of towns. At one station on each of the major routes unladen weights of goods vehicles were noted in section (L); classification according to unladen weight is the method used in licensing vehicles and it has been employed in previous economic studies. The details about numbers of axles and tyres in sections (M) and (N) are used in conjunction with the information in section (L) to correlate different methods of classifying goods vehicles.

Traffic census

While the survey was in progress, a census was taken of the number of vehicles passing in the direction of interviewing to determine the proportions of the different classes of vehicle sampled by the interviewers in each hour. In addition, a separate census was taken in the opposite direction to complete the census information required for general purposes. The method of classifying vehicles was the same as that used on the record-of-interview form. It was found that the enumerators experienced difficulty in seeing '20' plates on goods vehicles. The use of '20' plates as a method of classification is not normal in traffic censuses, but it was necessary in this case because it has been employed in speed studies by the Laboratory and it was used in the journey-time survey. (The problem will not arise in future because of the removal of the 20 mile/h limit.)

Coding of place-names

Some system of coding the places of origin and destination of journeys was necessary to permit analysis by punched-card techniques and, rather than construct a special system, the Ordnance Survey national grid reference system was

used. In this, a place-name is denoted by the six-figure reference number of the 1-km square in which it lies. The Ordnance Survey Gazetteer provided most of the references required but it was also found necessary to compile special lists for localities and postal districts in the London and Birmingham areas. In analysing the results of the survey, grouping into areas of journey terminations is required and, although the national grid system lends itself more easily to the use of rectangular rather than irregular areas, such as administrative areas, the latter may be used if required.

Staff requirements

The field-work was carried out in 8-hour shifts, the staff required per shift being

One station supervisor (who also acted as relief interviewer)
Two interviewers
Three census-takers (including one relief census-taker)
Two policemen.

In the case of policemen, the figure of two was an average rather than a standard requirement, and the number employed varied considerably according to the amount of traffic. In some cases it was sufficient to have only one man, relieved at intervals, to carry out the essential function of directing vehicles into the interviewing site. When traffic was heavy, however, an extra man was required to control the traffic and, in particular, to direct vehicles emerging from the interviewing site.

The total number of 8-hour shifts in the survey was 104, employing an average of eight men per shift, so that the total labour used in the field amounted to 832 man-days (using 'day' in this context to denote an 8-hour shift). In addition, the subsequent coding of place-names is estimated to have taken about 1½ man-days for each 8-hour shift of field work, bringing the total basic labour to 988 man-days. The field work was carried out by the six county authorities concerned, with the exception of the four nights' work which was done directly by the Laboratory. In most cases the stations were manned by engineering or clerical staff from the local authorities but in a few instances casual labour was engaged. The coding of place-names was also carried out by the county authorities.

The total number of interviews used in the analysis was 40 900, after the rejection of 471 forms on account of incompleteness, illegibility, etc. These figures exclude 92 drivers who had refused to supply information, i.e. only about 0·2 per cent of all drivers approached.

JOURNEY-TIME SURVEY

Journey times were measured by means of a test car on the 1800 miles of road shown in the map in Fig. 3. In addition to the various main routes between the London area and the Midlands, a large number of feeder roads were included and runs were also made as far north as Liverpool, Manchester, Sheffield and Leeds. The work was carried out during the spring and summer of 1955, the total distance travelled being about 5000 miles.

Field procedure

Because of the difficulty on rural roads of travelling at the mean speed of traffic, the procedure adopted was to follow a particular vehicle for about two miles, to

stop in a lay-by or other convenient place and then to commence following another vehicle; the procedure was repeated indefinitely in the same direction until the whole route was covered. An observer in the car noted down mileages and times of passing through towns and important road junctions. The watch used was of the 'cumulative' type, i.e. it could be switched off for the period during which the car was stationary, without the hand returning to zero. The reading on the watch at any instant was therefore the average journey time of the vehicles followed up to that point; this greatly simplified analysis of the results. The observer was responsible for correcting, as far as possible, for errors arising from the slowing down of the test car to a stop, and from the subsequent restarting; one system used was to switch off the watch halfway through the deceleration period and to switch it on when the speed of the test car had reached one-half of the estimated speed of the vehicle to be followed.

Personal bias in selecting the vehicles to be followed was avoided by the following technique. While the test car was stationary the observer made any necessary entries on the log sheet and referred to a map to check his position on the route. When he was ready, he gave a signal to the driver who thereupon turned his attention to the first vehicle to pass, and started to follow it. If the vehicle happened to be in a long bunch of traffic, it was sometimes not possible to follow it and a subsequent vehicle was taken instead. In following a vehicle it was unnecessary—and inadvisable—to follow closely behind it. The following-distance was allowed to vary throughout the run, although it was necessary to ensure that at the end of the run the time interval between the two vehicles was roughly the same as that at the start. The adoption of this procedure was desirable in the interests of safety as well as to avoid influencing the driver of the vehicle being followed. Frequently other vehicles were allowed to come between the followed vehicle and the test car.

Results for different classes of vehicle

Since on rural roads there are large differences between the mean speeds of the different classes of vehicle, it was necessary to obtain separate estimates of the journey times of light, medium and heavy goods vehicles. On route A.5/A.45, between London and Birmingham (the most important route in the investigation), four separate runs were made in each direction for each of the four classes of vehicle, making a total of 16 return runs. However, because of limitations in time and resources, work on other roads was limited to one run in each direction following cars only, the results for goods vehicles being estimated from those of cars. Other investigations by the Laboratory have shown that the speeds of cars are more sensitive to changing conditions than are the speeds of goods vehicles, and it has been established that the mean speeds of goods vehicles are closely correlated with those of cars.(1) The relations used to estimate the speeds of goods vehicles are shown in Fig. 6. This was based upon relations derived on level roads(1) with modifications to allow for the effect of rise and fall, as suggested by the results of the journey-time survey on route A.5/A.45, in conjunction with certain additional measurements.

The results of the survey were recorded on a map to show the average travel-time of cars on individual segments of road, in the same way as distances are shown on motoring maps. The map can be used to give the journey time between any particular origin and destination.

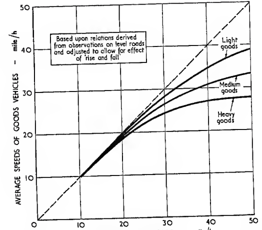


FIG. 6. Relations used to estimate average journey speeds of goods vehicles for the measured average journey speed of cars

Accuracy

Since the driver of the test vehicle was instructed to follow the first vehicle to arrive after the observer intimated that he was ready to proceed, the results were biassed in favour of vehicles coming after a long gap in the traffic; other investigations have shown that there is a tendency for such vehicles to travel faster than average. A check on the seriousness of this bias has been made by analysing data on vehicle timings obtained by the registration-number/stopwatch technique on a 1·2-mile stretch of A.5 north of Dunstable with a total flow of 700 vehicles per hour. The result was as follows:

Unweighted mean speed of cars	41·0 mile/h
Weighted mean speed of cars . . . . . . (weighting according to the length of time interval between each car and the preceding car on entering the section)	41·2 mile/h
Error in weighted mean speed	+0·2 mile/h

This calculation shows that the bias is present but that its effect is negligible.

Random error

The repeatability of the journey-time measurements was found to be better than might be expected, having regard to the crudeness of the method. On A.5/A.45 between St Albans and Dunchurch the results were as follows:

Class of vehicle	*No. of return runs*	*Mean time (min)*	*Standard error of mean time*
Car	6	94·6	1·1
Light goods . . .	4	109·0	1·3
Medium goods . .	4	117·5	1·0
Heavy goods · . .	6	129·5	3·0

These errors include the effect of differences in time of day and driving conditions during the different runs but exclude the effect of possible systematic bias in the method. The error in a journey-time measurement is, of course, a function of the magnitude of the journey time itself, and an analysis of data obtained on road A.1 showed that the standard error of the mean time in the two directions, based on one return run only, was about $0 \cdot 25\sqrt{T}$ minutes, where T is the journey time in minutes. For example, the standard error would be 1·25 minutes (5 per cent) in a journey of 25 minutes, 2·5 minutes ($2\frac{1}{2}$ per cent) in a journey of 100 minutes and so on.

SPEEDS ASSUMED ON THE MOTORWAY

Before the amount of traffic transferring to the motorway and the savings in time can be estimated, it is necessary to supplement the information about journey times on the existing road network with assumptions about speeds on the motorway. This presented some difficulty since there were no motorways in Great Britain on which to base the assumptions and since no suitable information was available about speeds on motorways in other comparable countries. Information from the United States of America suggested that the average journey speed of cars on American motorways is usually about 55 mile/h: it was, however, considered that it would not be valid to assume this figure in this investigation because of the differences between American and British vehicles. Further information from ordinary rural main roads in Britain and in America suggested that under comparable conditions the mean speed of British cars is about 5 mile/h less than that of American cars. It was therefore decided to assume a value of 50 mile/h for the mean journey speed of cars on the London–Birmingham motorway.

It seemed appropriate, at least as a first approximation, to use the relations given in Fig. 6 to obtain the speeds of goods vehicles corresponding to a value of 50 mile/h for the mean speed of cars. The values obtained were, after rounding off:

Light goods vehicles	40 mile/h
Medium goods vehicles	35 mile/h
Heavy goods vehicles	30 mile/h

Since the relations in Fig. 6 were derived from observations on ordinary roads on which goods vehicles are subject to speed limits, it was considered that the above values might not be applicable if speed limits were raised or removed on the motorway. (At the time of writing, the only motorway open to traffic—the Preston By-pass—has been freed from speed limits except for a 40 mile/h limit on vehicles towing certain types of trailer: the matter is still under review.) In any event it was considered that it would be instructive to study the sensitivity of the traffic predictions to the assumptions. Therefore, separate estimates of motorway flow and time savings were obtained for two additional sets of assumed speeds. The three sets of assumed values are given in Table 1, the variations being applied only to goods vehicles; with cars the value of 50 mile/h was retained throughout.

Table 1 also shows the mean journey speeds observed on that part of the existing route A.5/A.45 which the motorway will by-pass. The differences between the speeds on the existing road and the first set of assumed speeds show a marked gradation from cars at the upper extreme to heavy goods vehicles at the

Table 1

Mean journey speeds assumed on the motorway and observed on route A.5/A.45 (mile/h)

(The values refer to the average speed of vehicles while running)

Class of vehicle	Route A.5/A.45*	Assumed on motorway		
		1st assignment	2nd assignment	3rd assignment
Car	35	50	50	50
Light goods† (up to 1½ tons unladen)	31	40	45	50
Medium goods (1½ to 3 tons unladen)	29	35	40	45
Heavy goods (over 3 tons unladen)	26	30	35	40

* The part of the route to be by-passed by the motorway

† Coaches are assumed to have the same speed as light goods vehicles

lower extreme. This gradation is normally found when considering the effect of road improvements and it is implied in the relations in Fig. 6. The savings in time for a journey from London to Birmingham, as estimated from the assumed speeds, are given in Table 2.

Since the distance on the route using the motorway is different from that on the existing route (and for other reasons), Table 2 cannot be derived directly from Table 1. The values in Table 2 refer to estimated savings in actual running time. Commercial-vehicle schedules are calculated on the basis of assumed values for running speed and the savings in scheduled time may be rather different from those shown in the table.

Table 2

Estimated saving in time for a journey from Central London to Central Birmingham for different assumed speeds (present route: A.5/A.45) (minutes)

Class of vehicle	1st assignment	2nd assignment	3rd assignment
Car	30	30	30
Light goods . .	23	34	43
Medium goods .	20	35	46
Heavy goods . .	12	30	46

Speeds on European motorways

Although the above assumed speeds were adopted in the investigation they could not be regarded as completely satisfactory in view of the indirectness and scantiness of the evidence supporting them. The assumptions were therefore checked against information about speeds on motorways in Western European countries, where the character of traffic might be expected to be reasonably

similar to that in Great Britain. Since the information was not already available, the work was carried out directly by the Laboratory during the summer of 1957. The speeds of about 5000 vehicles were measured with a radar speedmeter at 15 sites on straight level sections of motorway in Belgium, the Netherlands, Germany and France.

Before comparing the information obtained with the assumed mean journey speeds on the London–Birmingham motorway, it is necessary to translate the latter into mean speeds on straight level sections of road. Two separate adjustments are required as follows:

(i) In this investigation, the term 'mean journey speed' has been used to denote the speed that produces the average journey time, i.e. it is the harmonic mean of the journey speeds. On the other hand, the arithmetic mean is the conventional method of specifying speeds measured at a point. The arithmetic mean is greater than the harmonic mean and the adjustments required to the assumed mean speeds have been calculated as ranging from +1·7 mile/h for cars to +0·9 mile/h for heavy goods vehicles.*

(ii) Journey speeds over long distances would be expected to be less than on straight level sections of road remote from junctions because of the effect of gradients and other factors. The average rise and fall on the London–Birmingham motorway will be about 45 ft per mile and, on the basis of the formulae derived from measurements on roads in Buckinghamshire,[1] this would produce expected reductions of about 1 mile/h in the mean speed of the average goods vehicle and about ½ mile/h in the mean speed of cars. However, since cars travel faster than goods vehicles, it is probable that they would be more susceptible to reductions in speed resulting from the presence of curves, access points, traffic signs, etc. Therefore, it would seem not unreasonable to assume that journey speeds of all classes of vehicle would be on average 1 mile/h less than speeds on straight level sections of road. This brings the combined adjustments required to the assumed mean journey speeds to about +3 mile/h for cars and about +2 mile/h for goods vehicles.

The adjusted values of mean speed are given in Table 3 together with the results of the speed measurements on the European motorways. The results in Table 3, which are also shown in Fig. 7, show that the mean speeds of the different classes of vehicle in each of the European countries follow a pattern similar to that found in Britain, i.e. there is a distinct gradation in the mean speeds obtained, from cars at the upper extreme to heavy goods vehicles at the lower extreme. The mean speeds of cars show surprisingly little variation from one country to another and the overall average value of 53 mile/h is equal to the value used in this investigation. However, when account is also taken of goods vehicles, the four European countries appear to fall into two groups—speeds are lower in France and Belgium than in Germany and the Netherlands; this tendency is particularly strong with goods vehicles but it is apparent, to a lesser degree, with cars. Moreover, the mean speeds obtained in France and Belgium correspond roughly to the lowest set of assumed speeds used in this investigation whereas those in Germany and the Netherlands are about equal to the second set of assumed speeds. The third set of assumed speeds is considerably higher than those observed in any of the countries in Europe and therefore it may be regarded as being of theoretical interest only.

* The distinction between the arithmetic and harmonic mean speeds corresponds with the distinction between time-mean speed and space-mean speed described by Wardrop.[2]

Table 3

Mean speeds on straight level sections of motorway: observed values in different European countries and assumed values on London–Birmingham motorway (mile/h)

EUROPEAN MOTORWAYS

Country	Car	Light goods (up to 1½ tons unladen)	Medium goods (2-axled)	Heavy goods (multi-axled)
Belgium*	52	40	38	35
France*	52	43	36	35
Germany†	54	46	40	38
The Netherlands†	53	45	41	40
Belgium and France combined	52	42	37	35
Germany and the Netherlands combined	54	45	41	38
Average for 4 countries	53	44	39	37

ASSUMED ON LONDON–BIRMINGHAM MOTORWAY‡

Assignment no.	Car	Light goods (up to 1½ tons unladen)	Medium § goods (1½–3 tons unladen)	Heavy § goods (over 3 tons unladen)
1	53	42	37	32
2	53	47	42	37
3	53	52	47	42

* Low mileage of motorway in these countries

† High mileage of motorway in these countries

‡ Mean speeds on straight level sections of motorway corresponding to assumed mean journey speeds

§ The method of classifying medium and heavy goods vehicles in the London–Birmingham motorway investigation was somewhat different from that used in the European speed measurements but other information suggests that this will have a negligible effect on the comparison.

The higher speeds in Germany and the Netherlands compared with those in France and Belgium cannot be explained by differences in speed-limit regulations since in all four countries motorways are either completely free or virtually free from legal speed limits (Appendix 5). Although there are many possible explanations for the differences in speed, the most likely explanation is that the greater mileage of motorways in Germany and the Netherlands may encourage the use of vehicles capable of higher speeds; in each of these countries motorways form a comprehensive network but in France and Belgium motorways are limited to a few isolated lengths. This suggests that the second set of assumed speeds, which correspond closely to the values obtained on motorways in Germany and the Netherlands, might be valid if the London–Birmingham motorway were being considered to be part of a motorway network. However, in this investigation the London–Birmingham motorway is being considered as an isolated length of motorway and therefore the first set of assumed speeds, which are about equal

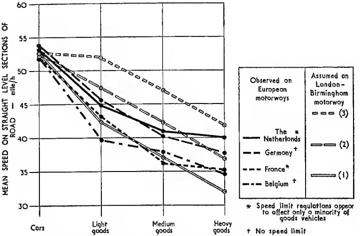


FIG. 7. Assumed mean speeds on London–Birmingham motorway compared with results for motorways in different European countries

to those on French and Belgium motorways, would appear to be more acceptable. For this reason and for simplicity, greater prominence has been given in the analysis to the estimates of traffic based on the first set of assumed speeds but the main estimates of traffic flow and time savings were produced for all three sets of assumed speeds.

METHOD OF ANALYSIS

The information on the interview forms, being already in code, was transferred directly on to the punched cards, one card for each interview. After sorting into appropriate groups the following additional information was gang-punched on to the cards:

'Sampling factor'
'Interception factor'
Saving (or loss) in journey time by transferring to motorway
Additional mileage incurred by transferring to motorway
Motorway access points used

'Sampling factors' and 'interception factors' were required because of the special methods employed in the origin-and-destination survey. The methods of obtaining them and the other items of information are described in the following paragraphs.

Sampling factors

The sampling technique used in the origin-and-destination survey meant that the proportion of vehicles sampled varied according to the flow of traffic and

the rate at which the interviewers worked. Therefore, separate sampling factors had to be calculated for each of the six classes of vehicle for each hour at each survey point. A sampling factor is found by dividing the number of vehicles of the particular class in the census by the number in the sample. Separate values for different hours of the day were necessary to avoid bias due, for example, to the variation in the proportion of potential motorway traffic at different times of day. Separate factors for different classes of vehicle were desirable to eliminate the effect of possible bias in the classes of vehicle selected for interview. This would probably have been unnecessary if the prescribed sampling technique had been strictly adhered to, but, as described earlier, it was noticed that on some occasions the technique was being departed from, and it was thought advisable to allow for this possibility throughout the work.

The overall average sampling factor throughout the survey was 3·3 but individual values varied considerably, being high when the flow was high. For example, at the point on A.45 between Coventry and Birmingham carrying about 6000 vehicles per day in one direction, the average factor was 7·2.

In using the results, each journey intercepted must be treated not as one journey but as 'x' journeys, where x denotes the sampling factor. Thus the number of journeys of a particular type at a survey point is found, not by counting the cards in the appropriate group, but by summing the sampling factors.

Interception factors

The use of interception factors was a device to enable the data on the punched cards from the various survey stations to be combined to give the best estimate obtainable from the data of the number of journeys per day between any particular origin and any particular destination. The method also avoided the necessity of having to carry out large amounts of manual computation.

Because of the variation in the concentration of survey points on different routes, the chance of a particular journey being intercepted depended upon the route taken. For example, journeys from London to Birmingham were liable to interception at ten points on route A.5/A.45, two points on route A.41 and one on route A.40/A.34 (Fig. 3). If these three routes were the only possible routes from London to Birmingham, the best estimate of the total number of journeys per day between London and Birmingham would be obtained by finding the average number of such journeys intercepted per station on each of the three routes separately, and summing the three values obtained. This calculation is arithmetically equivalent to allocating a weight of $\frac{1}{10}$ to journeys intercepted at each of the ten points on A.5/A.45, a weight of $\frac{1}{2}$ to journeys intercepted at each of the two points on A.41 and a weight of 1 to the single point on route A.40/A.34. These weights are here described as 'interception factors'.

In addition to the three routes mentioned above, there are many possible routes from London to Birmingham, consisting mainly of parts of the three main routes in conjunction with other roads. The use of interception factors must therefore be extended to take account of such routes. For example, a journey from London to Birmingham may be made via Aylesbury, joining A.5 at Towcester. This journey would miss the first six points of interception on A.5 but it would be liable to interception at survey station 90 between Aylesbury and Buckingham (Fig. 3). The interception factor for this point must therefore be $\frac{6}{10}$. By similar reasoning, interception factors were allocated to all of the survey

points as shown in Fig. 8. The values satisfy the condition that for all reasonable routes between London and Birmingham the sum of the interception factors is unity. Some allowance is made for circuitous routes, e.g. for vehicles starting out from London along A.1 to get to Birmingham.

The interception factors in Fig. 8 apply not only to London–Birmingham traffic but also to journeys with southern terminations in an area south and east of London and with northern terminations in the north-west Midlands, North Wales and Lancashire. For journeys with northern terminations in the north-east Midlands, Yorkshire, and further north, different factors had to be used. Separate sets of factors had also to be derived for journeys originating or terminating within the interception area. e.g. London/Northampton, Coventry/Luton, Dunstable/Daventry. A total of 147 sets of interception factors was found to be necessary and for each set the cards were sorted according to journey terminations. Further sorting was then required according to survey station before the interception factors could be gang-punched on to the cards.

The main advantage of using interception factors is that after they have been entered on the cards it is no longer necessary to consider the results from the different survey stations separately. For example, if it is required to find the number of journeys per day between a particular pair of journey terminations, the cards for all survey stations combined are sorted according to the entries in the journey-termination columns and the appropriate group of cards is selected. Since in one sense each card represents x journeys, where x is the sampling factor, and in another sense each card represents y journeys, where y is the interception factor, the total number of journeys is given by Σxy where Σ denotes summation over all cards in the group. This computation can be carried out automatically by punched-card machines.

Saving in journey time

For each of a large number of combinations of origin and destination, the mean journey time of cars on existing routes was derived from the journey-time map, the results for goods vehicles being estimated from those for cars as described on p. 9. Similarly, the journey time for the quickest notional route including all or part of the motorway was obtained, and the difference in time was entered on the appropriate group of cards. This procedure was carried out not only for journeys that would show an estimated saving in time by transferring but also for a large number of journeys with an estimated increase in journey time if they transferred to the motorway. The main reason for including such journeys is that they may be required in assessing the effect of assuming higher speeds on the motorway, which may convert a time loss into a saving, so that the journey may qualify for inclusion in the traffic assigned to the motorway.

Examples of estimated time savings are given in Table 4 for a selection of possible journeys, including journeys between the more important centres in the investigation. The maximum value in Table 4 is 44 minutes for a journey by car between Central London and Birmingham if the present route is on road A.41. The average saving to cars travelling from London to Birmingham, Coventry, Liverpool, Manchester and several other large centres in the Midlands is generally about 30 minutes. The values in Table 4 are averages for all vehicles of a particular class and the savings to individual vehicles may be greater or less than the average, depending upon the capabilities of the vehicles and the wishes of the drivers. For example, for a journey by car from Central London to Central

Birmingham at present using A.5/A.45, the saving of 30 minutes given in Table 4 is based upon the assumption that the journey speed on the motorway would be 50 mile/h, averaged over all cars. However, it has been estimated that an individual vehicle with a motorway speed of, say, 80 mile/h, may save as much as 50 minutes.

In general, the values in Table 4 show a downward gradation from cars at one extreme to heavy goods vehicles at the other extreme and, where the journey by the motorway is longer than by existing routes, cars may show a saving in time and goods vehicles a loss. Figure 9, which shows the estimated time saved by cars on journeys between London and a selection of places in the Midlands and the North, illustrates how the time saved reduces for the shorter journeys and for journeys not directly in line with the motorway.

In the analysis, the total savings in vehicle time to, say, all traffic assigned to the motorway, or to any other particular set of journeys, can be determined by computing $\Sigma\, x\, y\, z$, where x denotes the sampling factor entered on an individual card, y the interception factor and z the time saving, while Σ denotes summation over all the cards in the group.

Additional mileage incurred

Journey distances were measured in the journey-time survey and were included in the analysis in the same way as journey times. Table 4 shows that, for many journeys which must be considered as potential motorway journeys and which would take less time by transferring, the distance by the route including the motorway would be longer than by ordinary routes. Information about the changes in vehicle mileage is necessary in the economic assessment and, accordingly, the changes (usually increases) were entered on the punched cards.

Motorway access points used

In estimating the saving in time if a journey transferred to a route including the motorway, it was necessary to determine the points of entry to and exit from the motorway, and this information was entered on the cards. The information was used to predict the degree of usage of the various access points and the traffic flow on individual sections of motorway. This information also provided a convenient means of calculating the time savings for the higher assumed speeds on the motorway, without the necessity of repeating the whole analysis. Since the distance between each pair of access points was known, the incremental time savings could be calculated and added to the time savings produced by the first set of assumed speeds to give the time savings for the second and third sets of assumed speeds. There are 13 access points on the motorway including the three end points (Fig. 2) permitting 76 possible combinations of entry and exit points.

Traffic assignment

The expression 'traffic assignment' is used to denote the process of estimating the amount of traffic on a new road. The problem of deciding which journeys are likely to transfer from existing roads is often based on the judgment of the traffic engineer, but investigations in the United States of America into the origins and destinations of traffic on alternative routes are helping to put the subject on a scientific foundation.[3] [4] Typical results given in Fig. 10(a) show the percentage diversion to a new road for journeys with different time ratios (ratio of time via the new road to time on quickest alternative route). Usage of the new

Table 4

Time saved by using the motorway on journeys between certain origins and destinations

Journey	Present route	Average saving per journey (min)				Extra mileage per journey
		Cars	Light goods	Medium goods	Heavy goods	
London Central to						
Birmingham	A5/A45	30	23	20	12	2
Birmingham	A41	44	33	30	20	1
Birmingham	A40	41	31	28	18	−5
Bedford	*	11	10	10	11	−2
Coventry	*	30	23	20	17	2
Leamington	*	31	23	20	17	1
Leeds	*	−2	−5	−6	−6	4
Leicester	A5/A426	27	23	22	21	−4
Leicester	A5/A50	33	28	26	25	−3
Liverpool	*	31	23	20	16	3
Luton	*	13	10	9	7	−1
Manchester	*	29	19	15	11	6
Northampton	A5/A508	30	25	24	23	2
Northampton	A5/A50	33	28	26	24	−3
Nottingham	*	27	22	21	21	−4
Sheffield	*	−2	−4	−6	−5	4
Stratford-on-Avon	*	9	−1	−6	−13	9
Warwick	*	24	16	13	9	4
Slough to						
Birmingham	*	4	−7	−12	−19	13
Coventry	*	14	7	4	2	5
Leicester	*	11	6	5	4	0
Northampton	*	19	15	11	9	−2
Luton to						
Birmingham	*	18	12	11	10	1
Coventry	*	18	13	12	10	1
Leeds	*	−3	−3	−4	−3	1
Leicester	*	9	9	9	8	−4
Manchester	*	17	10	7	3	5
Northampton	*	15	14	14	15	−3
Bedford to						
Birmingham	*	9	2	−1	−6	7
Coventry	*	9	2	−1	−6	7
Manchester	*	8	−1	−5	−11	11
Liverpool	*	9	2	−2	−7	8
Northampton to						
Birmingham	*	5	4	3	2	1
Coventry	*	5	4	3	2	1
Manchester	*	4	0	−1	−4	4
Liverpool	*	6	3	2	1	1
Average for all journeys assigned to the motorway		16·2	10·8	12·1	9·7	1·7

* Quickest route

road drops gradually from 100 per cent for journeys that would take only half as long by transferring, to about 0 per cent for journeys that would take twice as long. For journeys with a time ratio of 1, denoting equal time on both routes, about 50 per cent use one route and 50 per cent the other.

The American studies also produced results similar to that in Fig. 10(a) but using other quantities in place of time ratio.(3) (4) These quantities included dis-

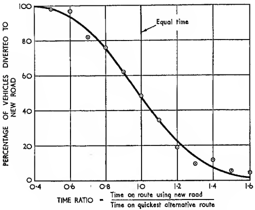


FIG. 10 (a). Typical American traffic assignment curve

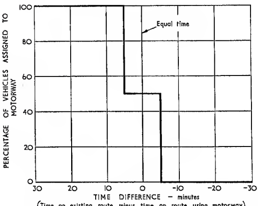


FIG. 10 (b). Assignment criterion used in this investigation

tance ratio, difference in time, difference in distance, and mileage of new road available, but the correlation was poorer than in the case of time ratio. Ideally, a composite function involving some or all of these variables should be used, but such a function would be difficult to derive and would require elaborate analysis to apply it to a problem in traffic assignment.

Because of the multiplicity of possible journeys in the present investigation and because of other difficulties, American methods were not used in assigning traffic to the motorway. Instead, assignment was based largely on the assumption that journeys that would save time by transferring will do so and that journeys that would lose time will not transfer. However, special consideration was given to journeys for which the estimated saving or loss in time was not appreciably different from zero. It would not have been logical to assign all journeys with an estimated saving of a few minutes and to reject all journeys with an estimated loss of a minute or two; in these cases it was assumed that 50 per cent of journeys will transfer and that 50 per cent will remain on existing roads. It is thought that estimates of traffic flow on the motorway produced by this simple method of assignment, which is illustrated in Fig. 10(b), will be similar to that which would be obtained by the more elaborate methods.

The process of traffic assignment was thus carried out for each of the three sets of assumed motorway speeds. The basic estimates were produced from the lowest set of assumed speeds and the results for the second and third assignments were derived from these by the calculation of differences.

RESULTS

Although three independent estimates of motorway traffic flow, time savings, etc., were obtained for the three sets of assumed motorway speeds, the lowest set appears to be the most realistic. For this reason, and for simplicity, the results given below refer to the traffic assignment based on the lowest set of assumed speeds. The main findings for the second and third assignments will be given later.

Since the traffic studies were carried out in 1955, the basic estimates of motorway flows and time savings have been produced for the traffic and road conditions encountered in that year. However, as described later, separate calculations have been made to assess the effect of subsequent traffic growth on the estimates and to predict the transfer of traffic to the motorway in 1960.

The following results are based, in the main, upon the Ministry of Transport and Civil Aviation's proposals for the London–Birmingham motorway at the time the traffic analyses were carried out, and they do not allow for later proposals to make certain minor additions to the northern end of the motorway (Crick spur and Dunchurch By-pass, shown in Fig. 1). Separate calculations have shown that, although these additions would alter the estimates of traffic flow on the more northerly sections of the motorway, the effect on the main features of the traffic investigation and the economic assessment would be negligible. However, allowance is made for the latest proposals in the section dealing with estimates of motorway traffic in 1960. A further point is that the traffic analyses refer to the effect of the motorway itself and they do not include the effect of the improvements to roads leading from the ends of the motorway to London and Birmingham, shown in Fig. 1. If these were taken into account,

the savings in vehicle time would probably be somewhat greater but it is thought that the estimated transfer of traffic to the motorway would be only slightly affected.

Table 5

Estimates of number of journeys, traffic flow, etc., on the motorway per day (16-hour weekday, June/July, 1955)

Class of vehicle	Number of journeys	Traffic flow on the most heavily-trafficked section of motorway	Average traffic flow*	Vehicle-hours saved	Additional vehicle-miles incurred
1. Car (leisure) .	4210	3430	2500	1130	9050
2. Car (business) .	5020	4030	2660	1360	8000
3. Light goods .	1290	950	630	230	1840
4. Medium goods .	4600	3800	2680	930	6130
5. Heavy goods .	3140	2710	2080	510	5800
6. Coach . .	260	230	160	40	690
All classes .	18 520	15 150	10 710	4200	31 510
Percentage of total contributed by medium and heavy vehicles (classes 4, 5, 6) . . .	43	44	46	35	40

* Vehicle-mileage on motorway divided by total length of motorway including eastern spur

Daily traffic estimates

Daily traffic estimates, time savings, etc., are given in Table 5, which shows that the number of journeys per day transferring to the motorway is estimated at about 18 500. These include journeys that would use only part of the motorway and the average traffic flow is therefore considerably less—about 11 000 vehicles per day. Medium and heavy goods vehicles constitute 46 per cent of the average traffic flow. The time saved by the traffic transferring to the motorway amounts to over 4000 vehicle-hours per day but, since on many of the journeys the distance is greater by the motorway, a total of more than 30 000 additional vehicle-miles is incurred per day.

The variation in traffic flow along the motorway is illustrated in Fig. 11, which shows that there is a tailing off in traffic towards the Birmingham end, the most heavily-trafficked section being just south of Luton (15 000 vehicles per day).

Table 6 shows that the average time saved for each journey transferring ranges from 16 minutes for cars to 10 minutes for heavy goods vehicles and coaches, the average for all classes of vehicle being about 13½. The average additional mileage incurred is 1·7. These results are overall averages for all journeys assigned to the motorway and the values for individual journeys cover a wide range depending upon length of journey and directness of route, as shown in Table 6. For example, the average saving in time is 30 minutes or more for a journey by car from London to Birmingham and for certain other long-distance journeys. However, most of the savings are considerably smaller than this and the average saving for all car journeys assigned to the motorway is 16 minutes.

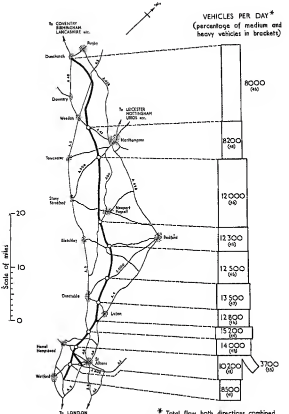


FIG. 11. Traffic flows on individual sections of the motorway

Motorway trip lengths

In Table 6 the average distance travelled on the motorway is given as 40 miles per journey out of the maximum of 66 miles; with goods vehicles, the heavier the vehicle the greater the distance travelled on the motorway. The heterogeneous nature of the journeys assigned to the motorway is illustrated in Fig. 12, which gives the distributions of journeys and of vehicle-mileage on the

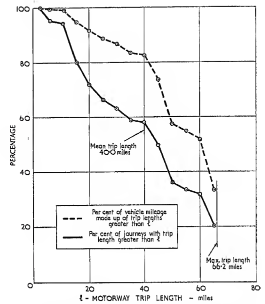


FIG. 12. Distributions of journeys and motorway vehicle mileage according to motorway trip length

motorway according to the length of the motorway trip. Figure 12 shows that journeys using the motorway for 60 miles or more constitute only about 30 per cent of all journeys but, since these journeys are longer than average, they contribute just over half of the vehicle-mileage on the motorway: 50 per cent of the trips are longer than 45 miles.

Table 6

Average time saved, additional mileage incurred, etc., per journey assigned to the motorway (16-hour weekday, June/July, 1955)

Class of vehicle	Average per journey		
	Time saved (min)	Additional mileage incurred	Distance travelled on motorway* (miles)
1. Car (leisure)	16·2	2·1	41
2. Car (business)	16·2	1·6	37
3. Light goods	10·8	1·4	34
4. Medium goods	12·1	1·3	40
5. Heavy goods	9·7	1·8	46
6. Coach	9·7	2·6	41
All classes	13·6	1·7	40
All light vehicles (classes 1, 2, 3)	15·5	1·8	38
All medium and heavy vehicles (classes 4, 5, 6)	11·1	1·6	43

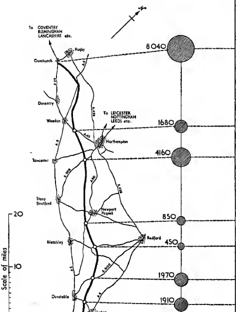
* The maximum distance is 66·2 miles (from Watford By-pass to Dunchurch). The total length of motorway, including the eastern spur, is 69·2 miles.

Usage of access points

The amount of traffic entering and leaving the motorway at each access point is illustrated in Fig. 13. Traffic using the three most southerly access points, which serve the London area, amounts to nearly 14 000 vehicles per day; the corresponding figure for the northern end point, serving Birmingham and Coventry, is about 8000 vehicles per day. The latter figure includes journeys terminating or originating in the north-west Midlands, Lancashire, North Wales, etc. Figure 13 also shows that the busiest intermediate access points are those serving Luton and Northampton.

Reduction in traffic on existing roads

Information about the expected effect of the motorway on the distribution of traffic on the road network is given in Figs. 14–16. Figure 14 gives daily traffic flows observed at the various interception points during the origin-and-destination survey; Fig. 15 gives the estimated traffic flows at these points if the motorway were in existence; the differences are given in Fig. 16. These results show that route A.5/A.45 is the most important contributor of traffic to the motorway, the reductions in traffic flow being around 5000 or 6000 vehicles per day, compared with the average motorway flow of about 11 000 vehicles per day. Table 7, which shows the estimated changes in traffic flow and vehicle-mileage on various segments of existing road, gives the reduction in vehicle-miles on



VEHICLES PER DAY USING EACH ACCESS POINT* (percent of medium and heavy vehicles in brackets)		
To or from access points further south	To or from access points further north	TOTAL
8040 (45)	—	8040 (45)
920 (20)	760 (34)	1680 (38)
3990 (41)	170 (43)	4160 (41)
550 (55)	300 (43)	850 (51)
330 (24)	120 (27)	450 (27)
1510 (50)	460 (50)	1970 (50)
610 (45)	1300 (43)	1910 (44)
2510 (33)	200 (10)	2710 (32)
—	1130 (40)	1130 (40)
60† (28)	220 (49)	280† (45)
—	3620 (53)	3620 (53)
—	1730 (40)	1730 (40)
—	8510 (40)	8510 (40)

* Total no. of vehicles entering and leaving motorway per 16-hour weekday, June / July 1955

† These figures are underestimates

FIG. 13. Usage of motorway access points

route A.5/A.45 as 330 000 per day, compared with the total motorway vehicle-mileage of 740 000 per day. The second most important route is A.41 between London and Birmingham with a contribution of 150 000 vehicle-miles per day. The other roads listed in Table 7 are individually of minor importance but collectively their contribution is as great as that of routes A.5/A.45 and A.41 combined. Although, in general, the motorway would reduce traffic on existing roads, the total net reduction being estimated at 710 000 vehicle-miles per day, the re-routing of journeys would cause flows to rise on roads leading to the motorway. The most striking example is on A.45 between the end of the motorway and Birmingham, where the estimated increase in flow was 3700 vehicles per day, equivalent to 110 000 vehicle-miles per day; the increases on other feeder roads amount to 160 000 vehicle-miles per day.

Table 7

Estimated changes in traffic on existing roads resulting from transference to the motorway

(*per* 16-*hour weekday, June/July,* 1955)

The estimates are approximate since exact details of routes taken were not obtained

Road		Approx. length (miles)	Net change in traffic flow (vehicles per day)	Net change in vehicle-miles per day (000's)
Reductions on long-distance routes				
A.5/A.45	St Albans–Dunchurch	60	−5500	− 330
A.41	London–Aylesbury–Banbury–Birmingham	105	−1400	− 150
A.40/A.34	London–High Wycombe–Stratford–Birmingham	110	− 600	− 65
A.4/A.423	London–Henley–Oxford–Coventry	100	− 500	− 50
A.6	St Albans–Luton–Bedford–Leicester	70	−1000	− 70
A.1	Barnet–Stamford	80	−1100	− 90
Reductions on subsidiary routes				
A.5	Weedon–Atherstone–Tamworth	40	−1900	− 75
A.5	Elstree–St Albans	10	−2500	− 25
A.6	Barnet–St Albans	10	−4000	− 40
A.413	Denham–Aylesbury–Towcester	55	− 500	− 30
A.50	Hockliffe–Newport Pagnell–Northampton	30	− 800	− 25
A.600	Welwyn–Bedford	25	− 800	− 20
A.428	Northampton–Coventry	30	− 300	− 10
Increases on other roads				
A.45	Dunchurch–Coventry–Birmingham	30	+3700	+ 110
—	Others	350	+ 500	+ 160
Overall net change in vehicle-miles on existing roads				− 710*

* The motorway vehicle-mileage of 740 000 exceeds the net reduction on existing roads by 30 000, because of the increased length of some journeys on transferring to the motorway

Purpose of journey

In the results given in most of the tables, private cars are classed as 'leisure' or 'business'. This is a simplification of the classification used in the origin-and-destination survey, and the distribution of car journeys, according to the more detailed classification, is shown in Table 8. The two categories of business journeys together constitute 54½ per cent of the total whereas journeys for private reasons constitute 41 per cent. Journeys to or from places of work constitute only 4½ per cent of all journeys and have elsewhere been included in the category 'leisure'.

Table 8

Purpose of journey of private car drivers assigned to the motorway
(16-hour weekday, June/July, 1955)

In other tables, the classification has been simplified to 'Business' and 'Leisure'

Category No.	Purpose of journey	No. of journeys	Percent of total
2	Business-expenses paid by employer	3740	41½
3	Business-expenses paid by self	1150	13
1	Private reasons	3670	41
4	Travelling to or from place of work	430	4½
5	None of above categories	230	*
—	Refusals to reply	10	*
	Total	9230	100
2 and 3	Business	5020	54½
1 and 4	Leisure	4210	45½

* Redistributed over the other categories

Occupancy of vehicles

The average numbers of adult occupants carried in the different classes of vehicle are given in Table 9. The values, which include the driver, range from 25 for coaches to 1·2 for medium and heavy goods vehicles. The average occupancy of a car is 1·8, but cars on leisure carry on average more occupants than cars on business. Table 9 also shows that coaches constitute only 1½ per cent of all journeys transferring to the motorway but carry about 20 per cent of all adult occupants of vehicles.

Night traffic

Information obtained by interviewing drivers throughout the night at two of the 23 survey points was used to provide estimates of night-time traffic on the motorway. These are compared with the day-time traffic estimates in Table 10, which shows that the night traffic (10 p.m. to 6 a.m.) is just less than one-sixth of the day-time traffic. The importance of heavy goods traffic at night is illustrated by the fact that the proportion of medium and heavy vehicles is 77 per cent at night compared with 46 per cent by day; the average hourly flow of heavy goods vehicles during the night is only slightly less than the average during the day. No measurements of journey times were made at night and in preparing Table 10

it was assumed that journey times at night are the same as during the day. This has probably resulted in some overestimation of the benefits of the motorway to night traffic but it will produce a negligible error in the estimates of total benefits.

Table 9

Occupancy of vehicles on journeys assigned to the motorway
(16-hour weekday, June/July, 1955)

Class of vehicle	Adult occupants per vehicle (including driver)	Vehicle-journeys by each class of vehicle (per cent)	Occupant-journeys by each class of vehicle (per cent)
1. Car (leisure) . . .	2·1	22½	25
2. Car (business) . .	1·5	27	22
Cars (all) . . .	1·8	49½	47
3. Light goods . . .	1·6	7	6
4. Medium goods . .	1.2	25	16½
5. Heavy goods . . .	1·2	17	11
Goods (all) . . .	1·3	49	33½
6. Coach	25·1	1½	19½
All classes . .	1·8	100	100

Table 10

Comparison of day and night estimates
(weekdays, June/July, 1955)

Class of vehicle	Traffic flow on motorway*		Vehicle-hours saved		Additional vehicle-miles incurred		Journeys with motorway trip-lengths more than 60 miles (per cent)	
	16-hour day	8-hour night	16-hour day	8-hour night	16-hour day	8-hour night	16-hour day	8-hour night
1. Car (leisure) . .	2500	230	1130	90	9050	940	33	43
2. Car (business) .	2660	130	1360	80	8000	690	27	44
3. Light goods . .	630	30	230	10	1840	250	25	71
4. Medium goods .	2680	400	930	150	6130	1380	32	54
5. Heavy goods . .	2080	890	510	200	5800	4760	41	72
6. Coach . . .	160	40	40	0	690	200	23	14
Total .	10 710	1720	4200	530	31 510	8220	32	60
Per cent of total contributed by medium and heavy vehicles (classes 4, 5, 6)	46	77	35	66	40	77	—	—

* Averaged over whole of motorway

Annual traffic estimates

Table 11 gives the ratios of 24-hour day traffic to 16-hour day traffic. The data were derived from information obtained by interviewing drivers at night (10 p.m. to 6 a.m.) as well as by day at a point on A.5 and a point on A.1.

Table 11

Ratios of 24-*hour traffic to* 16-*hour traffic* (*weekdays, June/July,* 1955)

Class of vehicle	24-hour totals divided by 16-hour totals		
	Traffic flow or number of journeys	Vehicle-hours saved	Additional vehicle-miles incurred
1. Car (leisure)	1·09	1·08	1·10
2. Car (business)	1·05	1·06	1·09
3. Light goods	1·05	1·05	1·13
4. Medium goods	1·15	1·16	1·23
5. Heavy goods	1·43	1·40	1·82
6. Coach	1·27	1·12	1·29
Weighted mean	1·16	1·13	1·26

Table 12 shows the relation between traffic on a weekday in June or July and traffic on the average weekday and weekend throughout 1955, as estimated from census data as follows:

(i) Automatic counter on A.5 north of St Albans recording continuously throughout 1955.

(ii) A manual classified count on a Friday, Saturday and Sunday at quarterly intervals at a point on A.5 and a point on A.45.

(iii) Ministry of Transport and Civil Aviation census data, August, 1954.

Table 12

Ratios of annual average weekday and weekend traffic to June/July weekday traffic

Class of vehicle	Average weekday ÷ June/July weekday	Average Saturday ÷ June/July weekday	Average Sunday or Bank Holiday ÷ June/July weekday
1. Car (leisure)	0·79	1·85	2·73
2. Car (business)*	1·00	0·50	0
3. Light goods	0·89	0·56	0·34
4. Medium goods	1·00	0·34	0·12
5. Heavy goods	1·00	0·42	0·23
6. Coach	0·71	1·77	0·86
Weighted mean	0·95	0·73	0·65

* These ratios were assumed

The two groups of data given in Tables 11 and 12 are combined in Table 13 to produce multipliers for converting the 16-hour day estimates for June and July to gross annual estimates. The result is shown in Table 14 in which the estimated annual transfer of traffic to the motorway is shown to be nearly 7 million journeys which save over $1\frac{1}{2}$ million vehicle-hours compared with existing routes and travel about 13 million extra vehicle-miles.

Table 13

Factors for expanding 16-*hour day, June/July, weekday estimates to gross annual estimates* (*including nights and weekends*)

The figures below are derived from Table 11 and Table 12 in conjunction with the following totals of the different types of day: Weekdays, 256; Saturdays, 52; Sundays, 52; Bank Holidays, 5

Class of vehicle	Traffic flow or numbers of journeys	Vehicle-hours saved	Additional vehicle-miles incurred
1. Car (leisure) . .	490	490	500
2. Car (business) . .	300	300	310
3. Light goods . .	290	290	310
4. Medium goods . .	320	330	350
5. Heavy goods . .	420	410	530
6. Coach	410	360	420
Weighted mean .	370	370	420

Table 14

Estimates of number of journeys, traffic flow, etc., on the motorway per annum (1955) (*including night and weekends*) (000's)

Class of vehicle	Number of journeys	Average traffic flow	Vehicle-hours saved*	Additional vehicle-miles incurred
1. Car (leisure)	2105	1225	554	4525
2. Car (business)	1506	798	408	2480
3. Light goods	374	183	67	570
4. Medium goods	1472	858	307	2146
5. Heavy goods	1319	874	209	3074
6. Coach	107	66	14	290
All classes	6883	4004	1559	13 085
Per cent of total contributed by medium and heavy vehicles (classes 4, 5, 6) . . .	42	45	34	42

* By traffic transferring to the motorway

Time savings to traffic on existing roads

So far only the savings in time to traffic transferring to the motorway have been considered but, since the reduction in traffic on existing roads would cause speeds to rise, the residual traffic would also benefit. In making the calculations, mean speeds observed in the journey-time survey were used in conjunction with speed/flow relations obtained in other investigations (e.g. in ref. 1). The procedure used for route A.5/A.45 is illustrated in Fig. 17 and the results of the calculations are given in Table 15. This table shows that the savings to the residual traffic amount to about 400 000 vehicle-hours per annum, i.e. about 25 per cent of the savings to the transferred traffic. Table 15 also shows that route A.5/A.45 accounts for roughly one-half of the total time savings.

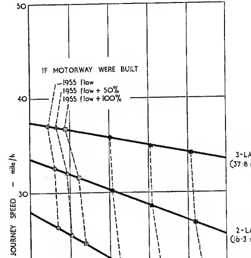


FIG. 17. Assumed speed/flow relations used in estimating time savings to traffic on A.5/A.45 between Elstree and Dunchurch not transferring to motorway

Table 15

Time savings to traffic transferring to motorway and traffic remaining on existing roads

Route used at present	Thousands of vehicle-hours saved per annum (1955)		
	Traffic transferring to motorway	Traffic remaining on existing roads	Total
A.5/A.45 . .	880	130	1010
Other routes . .	680	250	930
Total . .	1560	380	1940

Allowance for traffic growth

Traffic growth would, in the absence of the motorway, cause increased congestion on existing roads, so that the benefits resulting from the provision of the motorway would be correspondingly greater. Because of the difficulty of predicting the traffic flow in a specified year, particularly in the more distant future, estimates have been obtained for specified increases in traffic of 50 and 100 per cent above 1955 levels. The effect of changes in flow on speeds on existing roads has been estimated from speed/flow relations, as illustrated for route A.5/A.45 in Fig. 17. It was assumed that future increases in traffic on the motorway would not cause any reduction in speeds. For the range of flows encountered, i.e. up to about 30 000 vehicles per day in both directions combined for 100 per cent growth on the most heavily trafficked section of the

Table 16

Effect of future traffic growth on time-savings due to the motorway

—		Traffic level		
		1955	1955 + 50 per cent	1955 + 100 per cent
Average motorway traffic flow* (vehicles per 16-hour day, June/July, 1955)		10 710	16 065	21 420
Vehicle-hours saved per annum (millions)	Traffic transferring to motorway	1·56	3·60	6·78
	Traffic remaining on existing roads	0·38	0·90	1·60
	Total . . .	1·94	4·50	8·38
Number of journeys transferring to motorway per annum* (millions)		6·9	10·3	13·8
Time saved† per journey transferring (minutes) .		13·6	20·9	29·5
Additional vehicle-miles incurred per annum* (millions)		13·1	19·6	26·2

* Assumed to increase in proportion to the general traffic level
† Not including time saved on journeys remaining on existing roads

motorway, this assumption appears to be consistent with available evidence. The results, given in Table 16, show that increases in traffic cause a much more than proportionate increase in benefits. For example, if traffic is doubled the time savings are more than quadrupled, from about 1·9 to about 8·4 million vehicle-hours per annum. In preparing Table 16, no allowance was made for improvements carried out to existing roads since 1955, but since these were of minor importance compared with the motorway, the degree of overestimation in the benefits due to the motorway is negligible.

Estimates of motorway traffic in 1960

The London–Birmingham motorway is due for completion at the end of 1959; separate estimates have therefore been obtained of traffic flows on the motorway in 1960. These have been derived from the basic traffic estimates for weekdays in June/July, 1955, with an addition to allow for normal traffic growth. Although traffic trends have been somewhat irregular since 1955, because of the shortage and rationing of petrol during parts of 1956 and 1957, it is thought that a comparison between traffic flows in 1958 and in 1955 may provide a reasonably reliable indication of growth to 1960. Information from permanent automatic counters has shown the following average annual rates of growth (compound) in this period of three years:

National (Whole year, including weekends)	6·6 per cent
A.5, north of St Albans (Whole year including weekends)	6·1 per cent
A.5, north of St Albans (June/July, weekdays only)	5·4 per cent

It is probable that the differences between these figures are real because the numbers of goods vehicles, which constitute an unusually high proportion of the traffic on A.5, are known to have a lower rate of growth than cars. Therefore, in expanding the motorway estimates for weekdays in June/July, 1955, to weekdays in June/July, 1960, the value of 5·4 per cent per annum (compound) was assumed; this is equivalent to an overall growth of 30 per cent over five years.

In producing the 1960 estimates, allowance was made for the effect of recent proposals to extend the Birmingham end of the motorway for 1¾ miles to by-pass Dunchurch and to provide the 1¾-mile-long Crick spur (part of the proposed extension to Yorkshire). Since the Crick spur provides an alternative access point for certain types of journey, including those originating or terminating in Leicester and places further north and in areas north of Birmingham, it was necessary to alter the notional routing of some of the traffic using the more northerly sections of the motorway.

The 1960 estimates are given in the flow diagram in Fig. 18, which shows the variation in estimated flow along the motorway. Half way along, the flow is estimated at about 16 000 vehicles per day (both directions combined, 16-hour weekday, June/July) whereas, on the most heavily trafficked section south of Luton, the estimated flow is about 20 000 vehicles per day. The overall average traffic flow on the whole length of the motorway including the three spurs (74 miles in all) is estimated at 14 000 vehicles per day. On the 55-mile-long common trunk of the motorway from Beechtree junction to Kilsby (Watford Gap) junction, the average value is about 16 000 vehicles per day.

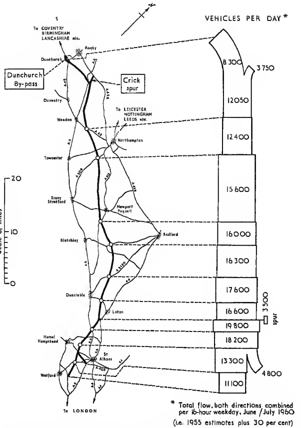


FIG. 18. Estimated traffic flows on London–Birmingham motorway in 1960

(These estimates refer to traffic transferring from existing roads. Generated traffic may increase the values by up to, say, 30 per cent)

Figure 18 shows that the London area is served by two separate limbs of motorway which join up further north to form the common trunk of the motorway. The estimated division of traffic between these two limbs is subject to a greater error than the combined figure, since in practice drivers will be influenced by factors that could not be taken into account in the traffic analysis—e.g. traffic signing, possible congestion on the approach roads and the extent to which the improvements on these roads have been carried out. Similar remarks apply to

the northern end of the motorway where the common trunk also separates into two limbs. Again, it is expected that the estimates of traffic on individual sections of the motorway would be subject to greater errors than the average value for the whole motorway.

Generated traffic

The estimates of motorway traffic flows given in this paper refer only to diverted traffic, i.e. journeys which have been assigned from existing roads to the motorway on the basis of certain assumptions. Experience in other countries has shown that new roads cause new journeys to be made; this generated traffic is usually attributed to journeys attracted from other forms of transport as well as to journeys previously not made at all. Prediction of generated traffic cannot be carried out with any degree of certainty but evidence presented in Part II of this paper suggests that on the London–Birmingham motorway generated traffic may constitute about 30 per cent of diverted traffic. Experience in other countries also shows that not all the generated traffic appears immediately the new road is opened to traffic but some develops in subsequent years.

Results for higher assumed motorway speeds

Up to now, consideration has been given only to the estimates of traffic and time savings obtained in the first traffic assignment, i.e. the estimation based upon the lowest of the three sets of assumed speeds on the motorway (see p. 11). The results obtained for all three assignments are compared in Table 17: they reveal that the estimated traffic flow on the motorway is not very sensitive to changes in the speeds assumed whereas the time savings are highly sensitive; for example, the traffic flow of all classes of vehicle combined is only about 15 per cent higher in the third assignment than in the first, but the total savings in vehicle time are about 80 per cent higher. The additional savings are entirely due to goods vehicles, the assumed speed of cars being the same for all three assignments. The additional distance incurred per journey is rather higher for the second and third assignments than for the first, presumably because higher speeds on the motorway would attract the less direct journeys. The average distance travelled on the motorway is about the same for all three assignments.

The insensitivity of the estimates of traffic flow to the speeds assumed indicates that within fairly wide limits the choice of assumed speed is of minor importance in predicting traffic flows. The more detailed analyses of traffic flows, given in this paper for the first assignment only, would be reasonably accurate even if the speeds on which they are based are underestimates. However, as already stated, the speeds assumed in the first traffic assignment appear to be more realistic than those used in the second and third. The second assignment was based upon speeds similar to those on motorways in the Netherlands and Germany, and it would probably not be applicable unless an extensive motorway system were provided in Great Britain. The speeds assumed in the third assignment are much higher than those obtained on the Continent and the estimates obtained in this assignment would therefore appear to be of theoretical interest only.

SAVINGS IN ACCIDENTS

Information about accident rates on motorways and on ordinary rural roads in various countries is compared in Table 18, which is based largely on data quoted by Smeed.(5) Despite the variability in these results, allowing for differences

Table 17

Summary of results of the three traffic assignments

(1955)

Class of vehicle	Assumed journey speed on motorway (mile/h)	Thousands per year				Average per journey		
		No. of journeys	Average traffic flow	Vehicle-hours saved*	Additional vehicle-miles incurred	Minutes saved*	Additional miles incurred	Distance travelled on motorway (miles)
1st assignment								
1. Car (leisure)	50	2105	1225	554	4525	15·8	2·1	41·0
2. Car (business)	50	1506	798	408	2480	16·3	1·6	36·7
3. Light goods	40	374	183	67	570	10·7	1·5	35·1
4. Medium goods	35	1472	858	307	2146	12·5	1·5	41·6
5. Heavy goods	30	1319	874	209	3074	9·5	2·3	48·1
6. Coach	40	107	66	14	290	7·9	2·7	40·0
All classes	—	6883	4004	1559	13 085	13·6	1·9	41·3
Per cent of total contributed by medium and heavy vehicles (classes 4, 5, 6)	—	(42)	(45)	(34)	(42)	—	—	—
2nd assignment								
1. Car (leisure)	50	2105	1225	554	4525	15·8	2·1	41·0
2. Car (business)	50	1506	798	408	2480	16·3	1·6	36·7
3. Light goods	45	426	200	107	781	15·1	1·8	33·7
4. Medium goods	40	1750	982	548	3383	18·8	1·9	40·1
5. Heavy goods	35	1615	1037	555	4560	20·6	2·8	47·7
6. Coach	45	133	78	29	504	13·1	3·8	41·1
All classes	—	7535	4320	2201	16 233	17·5	2·2	41·0
Per cent of total contributed by medium and heavy vehicles (classes 4, 5, 6)	—	(46)	(49)	(51)	(52)	—	—	—
3rd assignment								
1. Car (leisure)	50	2105	1225	554	4525	15·8	2·1	41·0
2. Car (business)	50	1506	798	408	2480	16·3	1·6	36·7
3. Light goods	50	461	215	144	930	18·7	2·0	33·1
4. Medium goods	45	1957	1092	756	4468	23·2	2·3	38·6
5. Heavy goods	40	1810	1134	830	5861	27·5	3·2	45·4
6. Coach	50	152	94	46	628	18·2	4·1	42·9
All classes	—	7991	4558	2738	18 892	20·6	2·4	40·2
Per cent of total contributed by medium and heavy vehicles (classes 4, 5, 6)	—	(49)	(51)	(60)	(58)	—	—	—

* By traffic transferring to the motorway

Table 18

Accident rates and fatality rates on motorways and ordinary roads in various countries

Motorways	Personal-injury accidents per million vehicle-miles	Fatalities per hundred million vehicle-miles	Ordinary roads	Personal-injury accidents per million vehicle-miles	Fatalities per hundred million vehicle-miles
U.S.A.			*U.S.A.*		
New Jersey Turnpike 1951	0·9	—	New Jersey undivided highways .	—	14
1952	—	6			
1954	0·3	2·5			
1956	—	2·3			
1957	—	2·0			
Expressways, Connecticut .		3	Ordinary dual carriageways, Connecticut . .	—	8
Riverside Drive and Arroyo Seco, 1941, 1944, 1947	0·7	2·5	Rural State highways, California 1941	1·2	15
			1944	1·0	14
			1947	1·1	10
Pennsylvania Turnpike			Main rural roads 15 States, 1946	1·2	11
1944–53	—	6–12			
1954	—	4	All rural roads		
			1940	—	14
			1950	—	11
			1954	—	9
France			*France*		
Autoroute de L'Ouest 1953	1·5	11	All roads (rural and urban) . .	—	27
1954	—	8·4			
1955	—	8·3			
1956	—	17·1			
Belgium			*Belgium*		
Motorway No. 10	—	10	Road No. 1 .	—	14
			Road No. 2 .	—	21
Germany					
Autobahnen (including some non-injury accidents) . .	1·1	—			
Great Britain			*Great Britain*		
			Rural roads in Buckinghamshire 1946–47	2·0	9
			Dual carriageways (rural areas in England) 1952–53	1·6	6
			Coinbrook By-pass 1947–52	2·8	23
Assumed on London–Birmingham motorway .	(0·9)	(6)	Road A.5 in rural areas of Herts., Beds., Bucks. and Northants. 1956	1·8	17

between countries, the number of fatalities per mile travelled on motorways is roughly one-third of that on ordinary rural roads, and the number of personal-injury accidents per mile travelled is roughly one-half of that on ordinary main roads. Assuming that these relations would also hold in Britain, accident rates on the London–Birmingham motorway have been estimated from the observed accident rates on rural sections of road A.5 in 1956; these are also given in Table 18. The assumed values of six fatalities per 100 million vehicle-miles and 0·9 personal-injury accidents per million vehicle-miles lie between those obtained on American motorways and those on Continental motorways.

More detailed information about accident rates on A.5 is given in Tables 19 and 20. These data refer to the part of A.5 in Hertfordshire, Bedfordshire, Buckinghamshire and Northamptonshire, which contains most of the 68-mile-long section of the main London–Birmingham route A.5/A.45 to be by-passed by the motorway. Table 19 shows that the accident rate per million vehicle-miles has shown some tendency to drop over the years, the overall average for the years 1953–56 being 2·4; accident rates are about twice as high in built-up as in non-built-up areas, the average value of 1·9 personal-injury accidents per million vehicle-miles in non-built-up areas being similar to results obtained in other investigations on rural roads.

Table 19

Personal-injury accidents per million vehicle-miles on road A.5 in different years (accident frequencies in brackets)

Year	Built-up	Non-built-up	Built-up and non-built-up
1953	4·1 (147)	2·0 (250)	2·5 (397)
1954	4·8 (186)	1·9 (261)	2·6 (447)
1955	4·5 (187)	1·8 (271)	2·3 (458)
1956	3·6 (157)	1·8 (274)	2·2 (431)
1953–1956	4·2 (677)	1·9 (1056)	2·4 (1733)

Table 20

Accident rates per million vehicle-miles for different classes of personal-injury accident on road A.5 in 1953–56

Class of accident	Built-up	Non-built-up	Built-up and non-built-up
Fatal	0·16 (26)	0·14 (79)	0·15 (105)
Serious	1·3 (202)	0·7 (417)	0·8 (619)
Slight	2·8 (449)	1·0 (560)	1·4 (1009)
All classes	4·2 (677)	1·9 (1056)	2·4 (1733)

Estimates have been obtained of the reductions in the number of casualties of different types, as well as in the total number of personal-injury accidents, a full statement of the assumed accident and casualty rates being given in Table 21. In the absence of information about accidents on the other roads that contribute traffic to the motorway, the rates obtained for A.5 have been assumed to apply to them also.

Table 21

Assumed accident and casualty rates on the motorway and on ordinary roads

—	Number per million vehicle-miles	
	Ordinary roads*	Motorway†
Personal-injury accidents	2·2	0·9
Casualties		
Fatal	0·15	0·06
Serious	1·2	0·6
Slight	2·1	0·8
Total	3·45	1·46

* Rates observed on road A.5 (built-up and non-built-up areas combined) in 1956. Assumed to apply also to other roads contributing traffic to the motorway.

† Assumed to be one-half of the rate on rural parts of A.5 except in the case of fatalities, for which one-third of the rate on A.5 is used.

The estimated annual savings in accidents and casualties given in Table 22 show that, on the basis of 1955 traffic, the savings are estimated at 340 personal-injury accidents per annum involving 24 fatalities and 155 serious injuries. In allowing for future traffic growth, it cannot be assumed that savings in accidents would increase in proportion to the traffic, since experience shows that increases in accidents, particularly the more serious accidents, are smaller than increases in traffic flow.[6] It was assumed that p per cent increase in traffic on existing roads would be accompanied by

$0 \cdot 3\, p$ per cent reduction in the number of fatalities per 10^6 vehicle-miles

$0 \cdot 2\, p$ per cent reduction in the number of serious casualties per 10^6 vehicle-miles

0 per cent reduction in the number of slight casualties per 10^6 vehicle-miles

$0 \cdot 1\, p$ per cent reduction in the number of personal-injury accidents.

These assumptions were based upon relations between changes in casualties in England and Wales between 1952 and 1956 and the corresponding change in traffic flow. The assumptions have been applied to existing roads but not to the motorway since the absence of congestion on the motorway may permit accidents to rise in proportion to the traffic. Table 22 shows that, on the basis of these assumptions, the number of fatalities saved shows no tendency to increase with increasing traffic and serious casualties show only a slight rise.

The estimated savings given in Table 22 refer to traffic transferring to the motorway and do not include the effect on the traffic remaining on existing roads. Glanville and Smeed[6] have pointed out that the removal of traffic from existing

Table 22

Estimated annual savings in accidents to traffic transferring to the motorway

—	Number saved per annum		
	1955 traffic	1955 traffic + 50 per cent	1955 traffic + 100 per cent
Personal-injury accidents .	340	468	562
Casualties			
Fatal . . .	24	26	23
Serious . . .	155	184	180
Slight . . .	342	514	684
Total . .	521	724	887

roads following the building of a motorway would be expected to increase the speed of traffic and might cause a small increase in the number of accidents per million vehicle-miles and a rather greater increase in the severity of accidents. There is no direct information on this point but a rough estimate has been made, based on the above assumptions but applied to traffic reductions rather than increases: the calculations showed apparent increases of 27 personal-injury accidents, 6 fatalities and 35 serious casualties per annum (1955 traffic). Since these increases are small in relation to the savings to traffic transferring to the motorway and since the validity of the method is open to considerable doubt, the figures given in Table 22 have, however, been used in the economic assessment.

PART II. ECONOMIC ASSESSMENT

INTRODUCTION

PART II of this paper gives estimates of the economic return to be expected from the construction of the London–Birmingham motorway using the data given in Part I on expected traffic flow and time savings.

The economic value of a proposed investment can be expressed as the present value of the future stream of net benefits accruing to all affected by it, divided by the present value of its costs over its life. Less rigorously, the value of the investment may be indicated by expressing net annual benefits as a rate of return on the capital cost of the motorway (or by estimating the pay-off period, i.e. the time taken for the future benefits from the motorway, discounted back to the time of construction, to reach a sum equal to the capital cost). The rate of return may then be used for comparison with other forms of investment and with the rate of interest to assess whether the investment is worth-while.

Assigning monetary values to costs and benefits involves many difficulties, ranging from doubts about the behaviour of traffic to the elusiveness of the benefits involved, and many simplifying assumptions have therefore to be made. Some account of the limitations of and likely biasses in the calculations is given when the detailed estimates are set out, but some limitations and errors are inherent in the whole investigation. Thus, on the cost side, it is necessary to take the motorway (as planned and going forward) as given, without considering whether this is the best way to meet the demand for the motorway, i.e. the plan that maximizes net benefit per £ invested. It is possible, therefore, that the best plan has not been selected* and the maximum returns obtainable from a London–Birmingham motorway may not in fact be calculated.

The demand (or benefit) side of the investigation is approached by considering first the present demand and assuming that the existing prices of goods, alternative means of transport, incomes, etc., are given and that the motorway does not affect the technical development of vehicles. This agrees with the assumptions used in the traffic estimates but, as these are based on 1955, changes in prices between 1955 and the present (1958) must be allowed for as far as possible.

The basis of the analysis on the demand side is the estimates of time savings to vehicles under 1955 conditions, given in Part I for three different assumed speeds for vehicles on the motorway. No allowance has been made, however, for any increased congestion that might take place on access roads. The effects on traffic since 1955 of some slight improvements to the existing roads, and of the raising of the speed limit for heavy commercial vehicles, have also not been allowed for, so that, on these accounts, the following calculations slightly overestimate the demand for and benefits from the motorway.

Speed limits, which it is assumed will not be imposed on the motorway, are in themselves a complicating factor. Strictly, benefits from the physical provision

* It is intended to consider this question (in a separate study by Dr. M. E. Beesley) at a later stage, together with the question of the returns obtainable on different sections of the motorway; other subsidiary questions, which are important in their own right but which are too complex and numerous to be introduced here, will also be considered.

of the motorway should be distinguished from the effects of administrative measures, e.g. speed limits. In fact, commercial vehicles seem to be little affected by speed limits, and this complication can be ignored.

The general problem is to measure the hypothetical sum that the community would be prepared to pay for the motorway rather than not have it. There are two main classes of beneficiary, those using the motorway and those remaining on existing routes, who will benefit from the removal of traffic. Cost reduction by these classes will form the main element of demand for (or benefit from) the motorway, although certain other classes, such as persons living on existing routes, will benefit from the reduction in noise, smell, etc., from traffic; the motorway, as a new and publicized commodity, will probably be valued more on this account than as just so much more road space. To ignore social benefits of this kind suggests under-valuation of the motorway.

More serious omissions, arising from lack of evidence, are a direct estimate of the value of leisure time gained or the reduction in strain and fatigue to road users, and part, at least, of the gain from potential reduction in accidents. It is possible, however, to estimate the rate of return from the measurable items in this analysis and then to consider the contributions required from the unmeasured items in order to change the rate of return by a specified amount.

Further errors on the demand or benefit side arise from the method of assignment used. The traffic estimates, on which the following savings in costs are based, were developed on the assumption that road users will behave in response to reductions in journey time, transferring to the motorway or remaining on existing roads according to the alternative that minimizes their journey time. To estimate benefits, however, it is necessary to translate the resulting savings into savings in costs that would be made if road users acted to minimize the real costs of their journeys. The fact that the starting point for the calculations must be time savings means that the translation is not perfect and leads to a general under-estimation of benefits for the following reasons:

(i) Some vehicles might decrease their total costs by transferring to the motorway even though total journey time (and time-costs) might be increased. These vehicles have not been assigned to the motorway and their benefits are therefore excluded.

(ii) Some vehicles may gain in time-costs less than they lose in other operating-costs by transferring to the motorway, but these vehicles have nevertheless been assigned to the motorway and the estimates of benefits will include the net losses of these vehicles.

The time savings are, however, by far the biggest item recorded in the cost-changes and the under-estimation of benefits is probably small.

In reality, vehicles will behave in response to the costs that they actually incur —including fuel tax, which is specifically excluded from the costs recorded here. Fuel tax will mean that there will be losses in real terms because of the distorting effect of that tax; the exclusion of savings in fuel tax is, however, essential since such taxes must be levied in any case and their saving represents no net benefit to the community.

Again, the methods used in estimating traffic assign traffic between the motorway and existing roads on the assumption that speeds on existing roads will stay the same and estimate the resulting time savings (on the motorway and on existing roads) from such a distribution of traffic. In practice, however, the traffic transferring to the motorway will be affected by the fall in journey time on

existing routes and, if further approximations were to be made, it would be found that some of the traffic assigned to the motorway would have shorter journey times and be better off on existing roads than has been assumed, so that benefits are again under-estimated. Nevertheless, it is shown in Appendix 6 that because traffic tends to divide roughly into two blocks—long-distance traffic likely to benefit from using the motorway in any case, and short-distance traffic likely to be better off on existing routes—the degree of under-estimation cannot be large.

In general, the limitations and biasses inherent in the analysis point to a systematic under-valuation of the motorway, although the under-valuation is unlikely to be very great and certain omissions, such as the value of leisure time saved, can be allowed for in the manner explained above.

The procedure for estimating 'present' demand is therefore as follows: first, the measured cost-changes for vehicles are set out; then follow estimates of change in accident costs. At this point the capital cost of the motorway and its maintenance cost are set out: maintenance is deducted from the sum of measured savings. Generated traffic, i.e. the increase in traffic expected to follow the reductions in the cost of transport, and its savings, are then estimated and added to the net measured savings. Then 'present' demand is rounded off by considering the impact upon the savings of various possible assumptions about the value of time saved by persons not on business. A final section considers the effect of future demand—that is, future growth of traffic—upon benefits from the motorway; there the strict assumptions governing 'present' demand are relaxed.

TRAFFIC ASSIGNED TO THE MOTORWAY

Value of savings in persons' working time

First, the changes attributed to the vehicles that, following the assumptions already noted, will use the motorway are considered under the heads of journey time of vehicles and their occupants, operating-costs and accidents; then, under the same heads but in a single section of the text, the changes attributed to the vehicles that will remain on the old roads are considered. The alternative assumptions about speeds on the motorway which lead to differing assignments to the motorway are set out in Table 23.

Table 23

Assumed speeds on motorway
(mile/h)

Class of vehicle	1st assignment	2nd assignment	3rd assignment
Private cars	50	50	50
Light commercial vehicles (up to 1½ tons unladen weight)	40	45	50
Medium commercial vehicles (1½ to 3 tons unladen weight)	35	40	45
Heavy commercial vehicles (over 3 tons unladen weight)	30	35	40

Time savings: man-hours

Table 24 gives the savings in vehicle-hours and man-hours for each class of vehicle transferring to the motorway.

The time of occupants travelling as part of their work is valued (i.e. all categories in Table 24 except private car, non-business, and passengers in coaches) by the average hourly earnings of the persons involved, earnings making allowance for overtime hours and pay. Thus the average hourly earnings of the occupants are estimated and multiplied by the man-hours saved, assuming that all occupants of vehicles on business are working, and that no occupants of vehicles not on business are doing so.

Table 24

Annual savings in vehicle- and man-hours by vehicles transferring to motorway

Class of vehicle	Average occupancy, persons	1st assignment Vehicle-hours (000)	1st assignment Man-hours (000)	2nd assignment Vehicle-hours (000)	2nd assignment Man-hours (000)	3rd assignment Vehicle-hours (000)	3rd assignment Man-hours (000)
Private car							
Business*	1·5	408	612	408	612	408	612
Non-business†	2·1	554	1163	554	1163	554	1163
Light commercial vehicles	1·6	67	107	107	171	144	230
Medium commercial vehicles	1·2	307	368	548	658	756	407
Heavy commercial vehicles	1·2	209	251	555	666	830	996
Coaches							
Drivers	1·0	14	14	29	29	46	46
Passengers	24·1		337		699		1109
Totals		1559	2852	2201	3998	2738	5063

* The procedure used to distinguish business from other uses is described in the traffic studies in Part I, business being defined as journeys for which expenses are paid by traveller or traveller's employer on business account.

† Includes a small amount of journey to work. Four per cent of all private car trips only were recorded as journeys to work.

In April, 1957, the average hourly earnings of males employed in 'Goods Transport by Road' and in the 'Tramway and Omnibus' service (excluding London) were, respectively, 50·2*d.* and 51·6*d.*(7) The latter may be applied to the coach-driver category without difficulty. In the commercial-vehicle categories, however, the wages paid in each class of vehicle vary, and overall average earnings must be converted to averages appropriate for the three commercial-vehicle categories. Wage-rate data are unsatisfactory for this purpose, for they underestimate the earnings differential between the weight categories; as shown by Glover and Miller,(8) the average yearly mileage run by commercial vehicles increases sharply with increasing size, and the amount of overtime pay may also be expected to increase. Data collected from four sources in the Birmingham area—a British Road Services depot, an independent operator, and two firms with large 'C' licence fleets—suggest that the appropriate wages differential between the three categories is light: 100, medium: 115, and heavy: 137 (see

Appendix 7 for the calculations). The Ministry of Labour data refer to 'A' and 'B' licence holders only (thus excluding the British Road Services). Since wages for 'C' licence and 'A' and 'B' operation are probably similar, the Ministry of Labour average can be broken down by weighting the national total numbers of lorries in each of the three unladen-weight categories by the differential given above, thus deriving the average wage that must be paid in each category to yield the overall average of 50·2*d.* The averages are light: 42*d.*, medium: 48*d.*, heavy: 57*d.* The figures in Table 25 have been obtained by applying these averages to the data in Table 24.

Table 25

Annual value of working time saved
(£000's)

Class of vehicle	1st assignment	2nd assignment	3rd assignment
Light commercial vehicle	18·5	29·9	40·3
Medium commercial vehicle	73·6	131·6	181·4
Heavy commercial vehicle	59·6	158·2	236·6
Coaches	3·0	6·0	10·0
Totals	154·7	325·7	468·3

The only data available on the value of the working time of occupants of private cars on business use have been obtained from a survey of London travel carried out in 1954. In this survey, the average annual income of persons travelling in their working time by private car was £800; assuming an effective working year of 2000 hours, the average hourly income of such persons will be 8*s.*, or 9*s.* 9*d.* as adjusted to 1957 incomes. At this rate, the annual value of the time saved by occupants of cars on business use will be £298 000 for all three assignments. The total annual value of working time saved by transfer to the motorway will, therefore, be £453 000, £624 000 and £766 000, for the three assignments respectively.

The non-working time saved by the motorway, from Table 24, amounts in total to 1 500 000, 1 860 000 and 2 270 000 man-hours per annum for the three assignments respectively. As explained in the Introduction (page 43), no direct value can be placed on these items.

Value of savings in vehicle time

Because of the savings in the time of vehicles, the same volume of commerce can be carried on with fewer vehicles—assuming that the degree of utilization of all vehicles will not be changed by the motorway. There arise, therefore, savings in those costs in addition to wages that do not depend upon the vehicle-mileage run. This will apply only to vehicles for which an attempt may be made to minimize the number of vehicles used—hence private cars not on business are excluded from this calculation.

The total vehicle-hours needed to perform a given set of journeys consists of running time (when the vehicle is travelling from origin to destination) and time for loading, maintenance, fuelling, etc. To calculate the reduction in the number of vehicles consequent upon the savings in running time, it is necessary to know

the relation between these savings and the average total period each class of vehicle is utilized. Much of the non-running time will be unaltered by changes in running time, e.g. loading, the time needed to perform maintenance dependent on mileage, etc. British Road Services data* suggest that the recorded running time of vehicles in the over 3-ton unladen weight (U.W.) category is of the order of 3400 hours a year out of a total annual vehicle time of about 4000 hours. The difference—600 hours—is mainly spent on loading, transhipping and maintenance, and so in the main will be unaffected by changes in running time.† The chief item affected by changes in journey time is maintenance due to time spent on the road and not mileage (routine checks, painting, etc.) and is unlikely to have exceeded 100 hours a year. The 3400 hours, however, include drivers' rest periods which would be reduced by a shorter journey time; the saving may be estimated from the data mentioned above (loc. cit.) as about one-eighth of 3400. Hence the figure of 3400 for recorded running time on the road is reduced to 3000 hours for actual running time and the other elements of total vehicle time susceptible to alteration by savings in running time comprise 500 hours (400 + 100) or $\frac{1}{6}$ of journey time. Applying those calculations to the data of Table 24, the total number of vehicles saved in the over 3-ton U.W. class will be, for the first assignment, $\frac{209\,000 + \frac{1}{6} \text{ of } 209\,000}{4000} = 61$ lorries.

Vehicles in other U.W. classes are probably used for fewer total hours during the year. There is no direct evidence on this, but they are estimated to be about 3600 for the $1\frac{1}{2}$- to 3-ton U.W. class, and 2900 for the under $1\frac{1}{2}$-ton class. Similar calculations to those just performed, and extended to cover the three assignments, yield the figures given in Table 26.

Table 26

Reductions in numbers of vehicles due to savings in time

Class of vehicle	1st assignment	2nd assignment	3rd assignment
Light commercial vehicles	28	43	58
Medium commercial vehicles	100	178	246
Heavy commercial vehicles	61	162	238

From cost tables[9] published by the *Commercial Motor*, and on the assumption that the vehicles 'saved' followed the distributions of vehicles on A.5 given by Appendix 9, the aggregate capital costs represented by these vehicles are £334 000, £767 000 and £1 123 000 for the three assignments respectively. (This values the vehicles at the replacement cost less an allowance for scrap value.) The annual value of these capital sums (the annual value of the aggregate reduction in the capital outlays of firms owning lorries, i.e. interest on capital saved plus an allowance for risk bearing) may perhaps be put at 15 per cent. To the annual amounts so derived must be added the time-costs saved associated with

* Provided by A. A. Walters and the British Transport Commission, to whom thanks are due.

† The number of hours a year spent in maintaining lorries—approximately 300—corresponds closely to the estimate of Glover and Miller, *J. roy. statist. Soc., Series A*, 1954, **117** (3), 297–323, Table 7, "Mean number of whole days spent idle in the week for mechanical defects", when the over 3-ton U.W. classes spent about half a day a week—or, say, 250 hours a year.

the reduction in fleets (principally time maintenance and establishment costs as calculated from cost tables also). Table 27 summarizes these savings by vehicle class and assignment.

Table 27

Annual value of reduction in fleets
(£000's)

Class of vehicle	Type of saving	1st assignment	2nd assignment	3rd assignment
Light commercial . . .	Capital	3	4	6
	Other	1	1	3
Medium commercial . . .	Capital	16	27	38
	Other	6	11	15
Heavy commercial . . .	Capital	32	85	125
	Other	5	14	19
Totals . .		63	142	206

Private cars on business and coaches should, of course, be treated in the same way. No data for these classes are available by which to make calculations similar to those just made for commercial vehicles. But, for private cars, a rough approximation to the 'cars saved' might be made by dividing the 554 000 vehicle-hours saved (see Table 24) by 2000—to give 277 for all three assignments. Assuming an average car worth £500 net of purchase tax and scrap value, the capital saving is £138 500. The annual savings represented by this, and the other time savings through a reduction in the 'fleet', may be put at, say, £15 000 a year. Coaches are liable to have variable usage; but if, say, 5, 10 and 15 coaches are saved in the three assignments respectively, on similar lines, some £2000 and £4000 and £6000 a year may be added for each assignment. Hence the aggregate annual 'time savings' for the three assignments are £80 000, £161 000 and £227 000 respectively.

The maximum time saving expected in any one class of vehicle is about half-an-hour per journey, with an average saving of 14 to 20 minutes per journey for the three assignments; much of the total savings are therefore the product of small savings and many journeys.

It is sometimes argued that a reduction of half-an-hour in a journey of, say, 8 hours will not enable additional 8-hour journeys—or shorter journeys—to be undertaken, thus saving fewer resources than estimated. On the other hand, there may be travellers and operators who must tolerate wasted time of vehicles, etc., because additional journeys are not possible within conventional working hours. In this situation a small reduction in journey time of half-an-hour may enable additional journeys of several hours to be undertaken at little extra cost, thus saving more resources than predicted. In this connexion, the distance between London and Birmingham (about 110 miles) is such that a small reduction in journey time might lead to a considerable growth of return journeys instead of single journeys in one day, with consequent savings in transport costs.

Hence, there are compensating effects in divisibility of journeys. Moreover, the road transport industry is so flexible, and the scope for utilizing small savings in time for better loading arrangements, and other forms of re-organization, is probably so great, that it is unlikely that vehicle operators will be unable to take full advantage of economies resulting from time savings.

It is also possible that gains in time will sometimes accrue to lorry drivers and mates rather than to the firms that employ them, i.e. that schedules will not always be adjusted to take account of the new conditions. This extra leisure would have a value to the men concerned that would probably differ from the values calculated. It seems very unlikely, however, that schedules will not be adjusted in the vast majority of cases; on the contrary, the opening of a new road is probably the kind of change that is objective enough for both users and employers to agree that an adjustment is needed.

Value of savings in fuel consumption

Since one of the most important operating costs is fuel consumption, tests were carried out with several vehicles on the 84 miles of A.5 between the junction with A.41 and Lindley, near Nuneaton, and at various steady speeds on the Motor Industry Research Association test circuit at Lindley to simulate motorway conditions. The results of these tests and their application to the vehicles expected to use the motorway are given in Appendix 8.

The results of Appendix 8 are summarized in Table 28. A negative sign indicates a decrease, and a positive sign an increase, in fuel consumption and fuel costs. Thus it is estimated that the overall average annual saving in fuel costs due to the transfer of vehicle-mileage to the motorway will be £117 000, £84 000 and £18 000 respectively for the three assignments, equivalent to overall savings in fuel costs of about 10, 6 and 1 per cent respectively.

Table 28

Change in fuel consumption per mile on transfer to motorway

Class of vehicle	Percentage change in fuel consumption			Estimated annual change in fuel costs (£ 000's)		
	1st assignment	2nd assignment	3rd assignment	1st assignment	2nd assignment	3rd assignment
Small car	+ 3	+ 3	+ 3	+ 8	+ 8	+ 8
Large car	−16	−16	−16	−36	−36	−36
Light commercial vehicles	− 8	+ 2	+19	− 3	+ 1	+ 8
Medium commercial vehicles						
Petrol	− 4	+ 4	+12*	− 8	+ 9	+30*
Diesel	− 8	− 1	+ 6*	− 6	− 1	+ 6*
Heavy commercial vehicles						
Small diesels	−11	− 8	− 1	−16	−14	− 2
Large diesels	−34	−27	−19	−50	−48	−35
Petrol vehicles	−10	− 4	+ 4	− 6	− 3	+ 3
Total annual changes in fuel costs				−117	−84	−18

* Estimated change based on extrapolation of results

Table 28 is the result of processes that involve certain errors and approximations. A discussion of the more important of these, and a comparison with fuel-consumption tests on foreign motorways, follows.

The most important errors in Table 28 seem likely to arise from the diversity of vehicles and their drivers, and from the narrow range of vehicles and drivers tested. Although the average speeds of whole classes of vehicle (and the range of speed over which they are driven) may be predicted with considerable accuracy, it is difficult to place particular vehicles (and their drivers) in their correct place in the speed distributions for whole classes of vehicle. The problem may be illustrated by reference to the private cars tested.

It appears from the relative speeds of the small and large cars on the A.5 route that the large car is likely to travel faster than the small car on the motorway, but it is not possible to predict their respective speeds. The unreal assumption was made that the large and small car would travel at the same speed (50 mile/h) on the motorway, largely accounting for the different rates of change in fuel consumption of the two cars. In this case, errors in predicting the motorway speeds of the two cars are largely compensating. Thus, more realistic motorway speeds of 45 and 60 mile/h, or of 47·5 and 55 mile/h for the two cars, giving an average speed of about 50 mile/h for cars as a whole, will give net annual savings in fuel costs for cars as a whole of £25 000 and £28 000 respectively, much the same net saving as given in Table 28 (£28 000).

Errors of this kind will not necessarily be compensating and generally the assumption that all the vehicles in their class will travel at the same speed on the motorway will mean that the choice of a faster-than-average test vehicle as representative of its class will over-estimate savings in fuel consumption and the choice of a slower-than-average test vehicle will under-estimate savings in fuel consumption.

Similar considerations seem to apply to drivers. For the private cars, each of which was tested with three drivers, it may be seen from Table C (Appendix 8) that the drivers on the A.5 route, with some freedom of choice as to speed, form a consistent order of speed and fuel consumption on both vehicles, the faster drivers having the higher fuel consumption. From the data given in Table C, it therefore appears likely that the faster drivers would achieve the greatest savings in fuel consumption on transfer to the motorway and, in so far as faster-than-average drivers have been chosen, savings in fuel consumption on transfer to the motorway will be over-estimated and vice versa.

Particular errors in estimating changes in fuel consumption may arise from the unusual characteristics of some of the test vehicles. Thus the small car tested had rather low gearing, achieving only 13·0 mile/h per 1000 rev/min as compared with an average of 14·5 mile/h per 1000 rev/min for six common makes of car of between 800 and 1400 cc,[10] and making it less suitable and economical for motorway operation than the average small car. The second heavy commercial vehicle tested had a choice of 10 gears with very high gears available for use under motorway conditions. This vehicle shows by far the greatest saving under motorway conditions and being used to represent heavier diesels of more than 10 tons carrying capacity, not all of which have such a wide choice of gear ratios, will result in their savings in fuel being over-estimated.

In spite of the variability of drivers and vehicles, it is possible to detect some consistent pattern in comparisons between fuel consumption on ordinary roads and on motorways. Thus, in Fig. 19, fuel consumption per mile on motorways as a percentage of fuel consumption on ordinary parallel roads is plotted for 23 tests on motorways on the Continent and in the United States of America.[11] The data are plotted as frequency distributions for commercial vehicles and

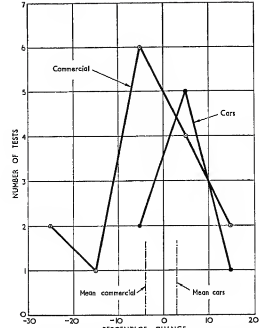


FIG. 19. Percentage change in fuel consumption per mile on motorways as compared with ordinary routes

private cars separately, and the diagrams show that, in spite of the many causes of variation, almost symmetrical distributions for both classes of vehicle are obtained, with a mean saving in fuel consumption of 4 per cent by commercial vehicles and a mean increase of 3 per cent by private cars. A comparison of these data and the results of the tests for the first assignment, given in Table 28, indicates that the fuel savings given by the tests are greater than those indicated by the foreign data, which suggest that little overall savings in fuel consumption per mile would be obtained by cars and commercial vehicles combined on transfer to a motorway. Although there is no reason to expect the fuel savings on the London–Birmingham motorway to conform closely to experience on motorways abroad, it is possible that savings in fuel consumption have been over-estimated by up to 10 per cent of the original fuel consumption, equal to an error of about £120 000 in savings in fuel costs. Additional error may arise from the estimation of the composition and characteristics of vehicles transferring to the motorway but most broad classes of vehicle tend to have rather similar fuel costs per mile (see Table H in Appendix 8) so that errors from this source are probably small.

For these reasons, a possible error of £120 000 is attached to the estimates of savings in fuel costs, these savings being more likely to be over-estimated than under-estimated.

Changes in other vehicle-operating costs

Apart from time and fuel costs, it is necessary to know the effect of transferring to the motorway on those items of cost susceptible to alteration by the change. Very general categories of cost found in published cost data, such as 'depreciation' or 'maintenance', are not sufficiently detailed for this purpose. In principle it is first necessary to isolate all costs that vary with vehicle-mileage and then to find out how these vary with changes in running conditions. In practice this would involve lengthy research into the wear and life of a whole variety of components under a variety of operating conditions. Research into the wear of individual components, each a small part of the total operating-costs, has usually been held not to be worth-while and very few data are available. Thus only the more important vehicle-operating costs are selected and their direction of change and probable orders of magnitude are indicated.

Tyre wear. According to tables of vehicle-operating costs,(9) tyre wear accounts for about 0·4*d.* per mile with private cars (about 10 per cent of operating costs, net of tax) up to 2·0*d.* per vehicle-mile approximately with heavy commercial vehicles (about 25 per cent of operating costs, net of tax). According to the researches in 1940–3 of Moyer and Tesdall(12) in the U.S.A., tyre wear is sensitive to vehicle-operating conditions. Their work indicates that tyre wear on private cars increases by about 40 per cent cumulatively for each increase in steady speed of 10 mile/h above 35 mile/h and that, at a speed of 35 mile/h, one stop per mile would increase tyre wear by 100 per cent. Thus it appears that on the motorway the greater tyre wear at the higher steady speeds of the motorway will tend to be compensated by the reduction in tyre wear resulting from the avoidance of stop-start driving and braking on ordinary routes. On average the test vehicles made about 0·1 involuntary stops per mile on the A.5 route and the small car, the only vehicle tested in this respect, made about one brake application per mile on that route.

In view of the compensating effect of these changes, it appears that the net effect on tyre wear is sufficiently small to be neglected at least at the speeds of the first assignment. At the speeds of the second and third assignments, the results of Moyer and Tesdall suggest a net increase in tyre wear, but their results are probably of limited relevance to modern British conditions; further research(13) has suggested that tyre wear is primarily determined by cornering (in association with speed) rather than by braking and by speed directly. It will be assumed, therefore, that there will be no net increase in tyre wear at the speeds of the second and third assignments, although this assumption may under-estimate the tyre costs to be expected on the motorway.

Brake wear. Although this item forms a small proportion of total vehicle-operating costs (probably less than 5 per cent) it is likely to be almost entirely eliminated on a motorway. Thus Saal,(14) in tests on motorways and on parallel ordinary routes in the United States of America, has shown that, on motorways, the time spent by a private car in braking is from 1/40 to 1/70 of that on ordinary routes.

It is difficult to estimate the savings from eliminating brake wear, but some idea of their order of magnitude may be obtained from examination of brake-lining

costs in trade catalogues. It appears that these are approximately £8 for a private car and a light commercial vehicle, about £30 for a medium commercial vehicle and about £40 for a typical heavy commercial vehicle, including fitting costs. Assuming that brake life is 30 000 miles on ordinary roads such as A.5, brake costs per vehicle-mile will be approximately 0·06*d.* per vehicle-mile for cars and light commercial vehicles, 0·2*d.* per vehicle-mile for medium commercial vehicles and 0·3*d.* per vehicle-mile for heavy commercial vehicles. Applying these costs to the vehicle-mileages transferred to the motorway given in Table I (Appendix 8) there is a possible saving of about £175 000 per annum for all three assignments. In addition, there will probably be some savings in clutch wear, so that it might be estimated that annual savings from these sources would be of the order of £200 000 for all three assignments. There may, however, be considerable error in this estimate.

Engine wear. Recent research[15] has indicated that the engine wear attributable to vehicle-mileage is very small, and that most engine wear (at least in the past) has been attributable to starting from a cold state. In terms of cost attributable to vehicle-mileage, therefore, engine wear is probably relatively small. Also, since it might be expected to change in about the same proportion as fuel consumption, the probable change will be small and any change in cost can be neglected.

Other vehicle-operating costs. Other vehicle-operating costs, such as wear on transmission and on other components, may be affected by operating conditions. Such costs are difficult to deal with, however, because the components in question may outlast, in an efficient state, the normal life of the vehicle and thus will not directly affect the relevant costs of operation, although they may, of course, affect its scrap value. This effect is likely to be small, however, and can be neglected.

The total annual changes in vehicle-operating costs other than fuel consumption are therefore likely to be a saving of about £200 000 for all three assignments, mainly due to reduction in brake and clutch wear.

Costs of additional vehicle-mileage incurred in transferring to motorway

The transfer of traffic from the existing routes will result in a net increase in vehicle-mileage in carrying out existing journeys. All this additional vehicle-mileage will be carried out on ordinary roads and it accounts for some 4·6 to 5·8 per cent of vehicle-mileage transferred to the motorway. The annual additional distance carried out by each broad class of vehicle (excluding coaches) in order to use the motorway for the three assignment assumptions is given in Table 29.

Table 29

Annual additional vehicle-mileage carried out by traffic transferring to motorway

Class of vehicle	Annual additional vehicle-mileage (000's)		
	1st assignment	2nd assignment	3rd assignment
Private cars	2010	7010	7010
Light commercial vehicles	570	780	930
Medium commercial vehicles	2150	3380	4470
Heavy commercial vehicles	3070	4560	5860
Totals	12 800	15 730	18 270

Table 30

Annual cost of additional vehicle-mileage incurred in transferring to motorway

	Additional vehicle-mileage (000's per annum)			Operating costs per mile of representative vehicle (net of tax) (pence)	Additional operating costs (£000's per annum)		
	1st assignment	2nd assignment	3rd assignment		1st assignment	2nd assignment	3rd assignment
Small car	4770	4770	4770	2·28	46	46	46
Large car	2240	2240	2240	3·11	29	29	29
Light commercial vehicles	570	780	930	2·57	6	8	10
Medium commercial vehicles							
Petrol	1330	2100	2770	5·48	31	47	63
Diesel	820	1290	1700	5·13	17	28	36
Heavy commercial vehicles							
Small diesels	1600	2370	3050	7·78	52	77	98
Large diesels	950	1410	1820	8·17	32	48	62
Petrol vehicles	520	780	1000	7·42	16	24	31
Totals	12 800	15 740	18 280		229	307	375

The annual cost of this additional vehicle-mileage may be calculated by splitting the mileages in the broad categories of Table 29 into the more detailed categories of Appendices 8 and 9 and applying operating costs per mile to the typical vehicles in the latter. The 'operating' costs concerned are those that vary with mileage—fuel, lubricants, tyres, and wear and tear attributable to mileage. The tables of operating costs published in *Commercial Motor*[9] have to be modified in two ways: costs are adjusted to exclude indirect taxes (fuel and purchase tax) and a figure for wear and tear must be estimated. In the published tables, wear and tear due to mileage is covered by two categories—'maintenance' (repairs and overhauls) and 'depreciation' (a notional figure based on the capital of the vehicles at current replacement values divided by an assumed mileage for the vehicle's 'life'). It is considered that the addition of these two would overestimate wear and tear due to mileage: this sum has therefore been adjusted downwards in each case on the basis of some very detailed costs* of road haulage covering some 50 vehicles in the medium and heavy classes. The resulting operating costs are given in Table 30.

The calculations in Table 30 show that the additional mileage costs—at £229 000, £307 000 and £375 000 for the three assignments respectively—comprise a considerable offset to the savings in operating costs (petrol, brakes and others) on the motorway.

TRAFFIC NOT ASSIGNED TO THE MOTORWAY

A computation similar to that done for the motorway traffic, of vehicles remaining on existing routes, should be carried out, but for the three assignments there will be savings to remaining traffic of only one-quarter or less the number of vehicle-hours saved by motorway traffic. Of the types of saving shown for motorway traffic (excluding extra vehicle-mileage)—time savings, fuel consumption, tyre wear, brake wear and other operating costs, all of which in principle are affected—only time savings seem worth pursuing. It is expected that the speed of traffic will rise slightly; this will give, in the aggregate, considerable time savings (380 000 vehicle-hours for all three assignments)—as traffic is 'drawn off' to the motorway less remains on the old roads, but hours saved per vehicle increase—and, in any case, the numbers drawn off are insufficient to affect the speed of the remaining vehicles very markedly (see also Appendix 6). But the effect on fuel consumption and on the rest of the operating-costs depends on the precise behaviour of the remaining traffic—if the time saved is caused by faster acceleration, longer bursts of speed and sharper braking, then costs may rise: if steadier speeds are achieved, they probably will fall. All mixtures of experience can be expected (in contrast to the motorway, where conditions will be much more uniform) and there is no means of saying how the average time saving will be divided among these possibilities. It seems best, therefore, to assume that operating costs will not change significantly, leaving time savings to be dealt with. The exact composition of the remaining traffic is not known (some of it will be in small towns, etc., not directly surveyed) but is unlikely to diverge far from the distribution left for A.5, etc., when traffic expected to transfer is taken away. Assuming this, and on the basis adopted above, these 380 000 vehicle-hours, representing some 500 000 man-hours, would be worth some £113 000 a year for labour costs plus £15 000 a year for vehicle time-costs, or a total of

* Kindly supplied by Mr. Myers of Myers Transport Co., Ltd.

£128 000 a year on all three assignments. Corresponding savings in non-working time, accounting for some 375 000 man-hours a year, will also be made. This again cannot be valued directly.

CHANGES IN ACCIDENTS AND THEIR COSTS

From data on accidents on existing routes and on accidents on motorways, it has been estimated that the transfer of vehicle-mileage from existing roads to the motorway will lead to a reduction in personal-injury accidents of 340 per annum at 1955 traffic flow, involving 24 fatal, 155 serious and 342 slight casualties. These reductions may be partly offset by an increase in the seriousness of accidents per vehicle-mile on existing routes after transfer has taken place, but this effect is expected to be small compared with the above savings, and it will, in any case, be offset by a probable reduction in non-injury accidents which have not been specifically allowed for.

Considerable problems are involved in estimating the costs of accidents in monetary terms, the true cost of which it is impossible to value fully, but adopting a method of valuing accidents in terms of loss of output, medical expenses, damage to property and administrative expenses(16) it is estimated that the annual savings in costs of accidents will be as given in Table 31.

Table 31

Estimated annual cost of accidents saved by motorway

Casualties and accidents saved per annum	Estimated unit cost (£)	Total annual cost (£)
Damage to property and administrative costs (340 accidents)	110	37 400
24 fatal casualties	2500	60 000
155 serious casualties	650	100 750
342 slight casualties	50	17 100
Total annual cost		215 250

It is expected, therefore, that the cost of accidents saved by the motorway at 1955 traffic flows will total about £215 000 per annum. Because of the inability to value such factors as suffering, sense of loss, etc., the true cost of accidents to the community is under-estimated by a valuation in monetary terms, but such a valuation does at least give a minimum monetary weight to savings in accidents.

RATE OF RETURN FROM INVESTMENT IN THE MOTORWAY

Costs of the motorway

Before putting together the calculations on the returns side, it is necessary to establish figures for the costs of the motorway—the original capital cost of construction and maintenance costs. The latter will be treated as deductions from the benefit side.

The estimated capital cost of the motorway is £22 460 000 of which £16 200 000 is for the 53-mile section from north of St Albans to Dunchurch and £6 260 000 for the 16-mile St Albans By-pass. This figure may be increased to £23 300 000 to allow for interest charges at the rate of 5 per cent per annum during

construction. It includes a sum for the land used, calculated at its value as agricultural land, its best alternative use, and includes costs of supervision, extraordinary damage and accommodation works.

Annual maintenance costs present some difficulty. The economic concept—accepting that the original construction costs are a datum, and thus independent of future maintenance—is simply the future expenditures needed to keep the road intact.* Difficulties occur in estimating these sums because no comparable road has yet been built in Britain. Some indication of maintenance costs, however, may be obtained from maintenance costs on ordinary roads. In 1957/8, expenditure on maintenance and minor improvements was £1539 per mile on trunk roads (17) with an average carriageway width of less than 30 ft. The carriageway width of the motorway is 72 ft (2 × 36 ft carriageways) with many bridges and special structures such as two-level junctions. It seems unlikely, therefore, that maintenance expenditure on the 69-mile motorway will be less than £200 000 a year. Maintenance expenditure of this magnitude should not occur in the early years of the motorway's life, but in these years the road will be depreciating to a state in which maintenance expenditure becomes necessary and provision should be made for it. Thus the provision for maintenance may be regarded as accumulating (at interest) until the expenditure is made. Nevertheless the figure of £200 000 seems to be reasonably conservative and should, in fact, allow for some reduction in maintenance costs on existing roads.

Benefits, excluding effects of generated traffic

It is now possible to set out the individual gains and losses resulting from the motorway, in so far as they have been measured. This is done in Table 32 for the three assignments, a negative sign indicating a saving in costs and a positive sign an increase in costs.

Table 32

Estimated savings (−) and increases (+) in annual costs resulting from construction of the motorway

	Changes in £000's per annum		
	1st assignment	2nd assignment	3rd assignment
Savings in working time by traffic transferring to motorway	−453	−624	−766
Reduction in vehicle fleets	− 80	−161	−227
Change in fuel consumption for vehicle-mileage transferred to motorway	−117	− 84	− 18
Change in other operating costs for vehicle-mileage transferred	−200	−200	−200
Costs of additional vehicle-mileage incurred in transferring to motorway	+229	+307	+375
Reductions in cost to vehicles remaining on old roads	−128	−128	−128
Total vehicle costs	−749	−890	−964
Reduction in accidents	−215	−215	−215
Maintenance costs of motorway	+200	+200	+200
Net annual measured savings	−764	−905	−979

* Providing for maintenance to keep the road intact avoids the need to provide for amortization, which is a financial device to re-pay loans or a provision to cover the risk that the road will not be required, at some future date. The risk seems negligible in this case.

Generated traffic and its benefits

The prospective fall in costs of road transport consequent upon investment in the motorway will lead to extra benefits accruing to users (of all affected roads) who will be able to make trips that are at present frustrated at the ruling levels of cost. To estimate this, it is necessary to use a combination of experience of generated traffic for motorways in the United States, and arguments derived from particular factors that appear to be likely to affect the outcome. Some 17 estimates of so-called 'generated' traffic on seven toll roads in the United States of America[18] range from 11 to 44 per cent of diverted (or transferred) traffic with an average of 24 per cent and with some tendency for generated traffic to increase in relation to diverted traffic with the passage of time, as would be expected, since the process being considered takes some time to work out in practice. Apart from the obvious differences between British and American conditions, the results cannot be directly applied to the motorway because a most important determinant of generated traffic—the time savings achieved by the new road in relation to the times of journeys actually carried out by traffic—is not given for the American data.

However, there is some evidence[18] that the volume of traffic between two points is inversely related to the distance or journey time between the two points giving a relation of the form:

$$Q = \frac{K}{T^n}$$

where Q = journeys per period between the two points;
K = a constant expressing the populations of the points, the level of commerce between the two points, etc.;
T = the journey time between the two points;
n = a positive exponent.

By using a relation of this kind and with knowledge of the values of the exponent n, of original journey time, and of saving in journey time, it is possible to estimate the additional traffic arising between two points owing to a reduction in journey time between them. By doing this for all journeys for which time savings will result, it is possible to estimate the vehicle-miles of generated traffic arising, and this may be expressed as a percentage of diverted vehicle-mileage. This has been done in Appendix 10 for a sample of journeys. (It is virtually impossible to cover all journeys between all origins and destinations for which time savings are likely to take place.) The journeys considered in Appendix 10 are the longer distance journeys between London and south-eastern England and points lying north of the terminal point of the motorway, accounting for about one-half of the journeys and about three-quarters of the vehicle-mileage expected to transfer to the motorway.

The chief difficulty in using this formula is, of course, setting a value on the exponent n. This should reflect the response of demand for road transport by individuals and firms as a result of prospective reductions in costs. In American and Swedish studies there is considerable evidence for an exponent of between 2·5 and 3·5,[18] for traffic between major centres of population. For two reasons in particular, an exponent of 3 should, it seems, be regarded as the outside limit for estimating benefits to the traffic dealt with here. The reasons are as follows:

So far as goods are concerned, the railways to which one would look to provide extra goods traffic on the roads have, apparently (in proportion to that already going on the road), very little traffic left that could be secured by road

transport. This is well brought out by a study of goods vehicles emanating from Birmingham, in which it is shown that it is precisely in the kind of runs covered by the motorway—e.g. Birmingham–London, Birmingham–Dagenham and Birmingham–Luton—that the proportion of total general traffic and merchandise going by road, as opposed to rail, was greatest in 1953.*

There may be a considerable diversion of passenger traffic from the railways; but the benefits to the community are likely at best to be small—and probably even negative—since passenger rail fares for the kind of journeys the motorway caters for (for example, Birmingham–London) exceed their marginal costs by a substantial amount.

The calculations in Appendix 10 show that, for the sample of journeys taken, an exponent of 3 gives generated traffic as 31 per cent of diverted traffic.

There may be considerable error in these estimates, however, in addition to the error involved in a simple summing up of a very complex process whereby many individuals and organizations make decisions as to their journeys, their mode of travel and their general expenditure. The sample of journeys used in Appendix 10 is biassed towards long-distance journeys, which are not fully representative of the traffic likely to be transferred to and be generated by the motorway. Thus it could be expected that the greatest relative gain (and the greatest generation of traffic in relation to diversion of traffic) would take place for journeys with origins and destinations near the terminal points of the motorway. For longer journeys than this, the relative gain from the motorway (and thus its power to generate traffic) will fall off because the time savings from the motorway as a proportion of journey time between origin and destination will fall. For journeys shorter than the total length of the motorway, a somewhat similar process will occur and the shorter the journey the more the traffic will have to go out of its way to use the motorway and the less the relative gains and the power to generate traffic of the motorway. But the sample used in Appendix 10 is such a high proportion of total journeys expected on the motorway that the error from bias in the sample is probably small.

The benefits accruing to generated traffic by its being able to undertake journeys that were not worth-while before may be estimated as follows. As generated traffic only comes into existence because of a reduction in road-transport costs, the journeys represented by this traffic are of less importance (to the persons or organizations making them) than existing journeys that were worth making at the original higher level of transport costs. On the whole, therefore, benefits to generated traffic are less than those to existing traffic, and the benefits to generated traffic per vehicle-mile may be put at, on average, about half those to existing traffic. Total net benefits to vehicle costs are given in Table 32 at £749 000, £890 000 and £964 000 for the three assignments respectively; the benefits to generated traffic thus work out at ½ of 30 per cent = 15 per cent of these, or £113 000, £136 000 and £147 000.

This extra traffic, in so far as it is carried on the motorway, will give rise to virtually no extra cost in road congestion but, in so far as it is carried on old

* A. A. Walters, Department of Commerce and Social Science, Birmingham University, "A report on traffic, costs and charges of freight transport in Great Britain", Table 6, p. 226 (unpublished report). This Table gives the proportion of combined British Railways and British Road Services monthly traffic flow to major destinations carried by each service, and includes flows from Birmingham to 22 towns throughout the country. London, Luton and Dagenham rank 16th, 21st and 22nd respectively—the railway carried 7 per cent of all traffic to Dagenham. And, of course, British Road Services even at its peak, in 1953, was not as large as the 'C' licence fleets which were necessarily excluded from this calculation.

roads, there may be some increase in costs to vehicles remaining there. The extra total traffic will affect accident costs adversely, and congestion will be somewhat increased on roads leading to the motorway. These offsetting costs, although in aggregate probably small, supply another reason for regarding the estimate for generated traffic as approaching the upper limits of possible benefits. The total net annual savings are thus increased by generated traffic to £877 000, £1 041 000 and £1 126 000 respectively.

In so far as generated traffic and its benefits have been measured and valued, the latter will include the benefits from the motorway arising from the development and better location of industry, housing, and other similar changes, associated with improvements in transport.*

Effect of unmeasured items on benefits

The savings so far recorded represent returns on the value of capital to be invested in the motorway (£23 300 000) of approximately 3·8 per cent, 4·5 per cent, and 4·8 per cent, for the three assignments respectively. There remain to be considered the items for which no specific measurement has been attempted. The factors, mentioned in the Introduction (p. 43), that the motorway is a new 'commodity' and that there are various 'social' benefits, which apply to road users in general, must be left as an unknown addition to the value of the investment. The most important items remaining are the savings in non-business time, amounting on the motorway to 1 500 000, 1 860 000 and 2 270 000 hours per annum for the three assignments and on the old roads to 375 000 hours, making totals for the three assignments of 1 875 000, 2 235 000 and 2 645 000 hours respectively. It is certain that these must be given a positive value, for, associated with reductions in journey time, there will always be some reduction in strain and fatigue; there will also be a reduction in the risk of accidents—part of the value of which, as seen earlier, has not been counted directly. However, the actual value of time saved to the people concerned will, of course, vary enormously with the situation in which they find themselves. The average values could thus be anywhere within a large possible range. Table 33 sets out the rates of return that would be reached if this average value were in the range 2*s*. to

Table 33

Rates of return including average values for non-business time saved

Average value of non-business time (shillings)	1st assignment	2nd assignment	3rd assignment
	Rate of return (per cent)	Rate of return (per cent)	Rate of return (per cent)
2	4·6	5·4	5·9
4	5·4	6·4	7·1
6	6·2	7·4	8·3
8	7·0	8·3	9·4
10	7·8	9·3	10·5

* The question of who ultimately benefits from the motorway must be distinguished from the question of measuring the original benefits. The latter may be diffused over a wide variety of interests—land-owners, industrialists, consumers, etc. Double-counting must also be avoided.

10s. The actual values concerned could only be found by experiments with charges upon the motorway when it is built, or by very complicated analogous experiments. There are many examples in Great Britain and in other countries of charging for the use of roads, but these have not established any values for non-business time. Most people might be inclined to say that the middle ranges of the table are most likely to be closest to reality in this case, i.e. the values for non-business time of some 4 to 8 shillings per man-hour. It is tentatively concluded, therefore, that the returns thus far investigated lie between 5·5 to 7 per cent for the first assignment, 6·5 to 8·5 per cent for the second, and 7 to 9·5 per cent for the third.

The discussion in the traffic study on the assumptions underlying the assignments concluded that the first assignment appeared to be the most realistic of the three. This was attributed partly to choice of users and partly to technical limitations to vehicles. The latter mean that the results for the third assignment are outside the bounds of possibility as far as present conditions are concerned. Economic considerations made the results of the second assignment a possibility. It may be tentatively concluded, therefore, that the rate of return at 1955 traffic volumes is of the order of 5·5 to 8·5 per cent.

FUTURE DEMAND AND FINAL ASSESSMENT

Effect of traffic growth on benefits

The effect of traffic growth on benefits from the motorway is considered in Part I in which it is estimated that an increase in traffic of 50 per cent above 1955 would increase the vehicle-hours saved by the motorway by about 130 per cent and that a 100 per cent increase in traffic would increase vehicle-hours saved by about 330 per cent. Not all of the savings or increases in costs given in Table 32 would increase in the same ratio as time savings but it is clear from these ratios that net benefits from the motorway will tend to increase approximately with the square of traffic flow. The evidence available (given in the traffic study, p. 34) suggests that the rate of increase in all motor traffic on main London–Birmingham routes may be put at about 6 per cent per annum between 1955 and 1958. Projecting this rate of increase in traffic into the future and taking the rate of return at 1955 traffic volume as between 5·5 and 8·5 per cent, rates of return at various future dates would be as given in Table 34. Similarly, if it is assumed that the motorway is completed by 1960 and a 6 per cent annual increase in traffic continues, and if future benefits are discounted back to that date by the rate of interest (assumed to be 5 per cent), it may be calculated that the motorway would pay for itself in about 6 to 8 years from that date, that is by about 1966–1968. There are of course many possible errors involved in projecting past increases in traffic into the future; rates of increase may change and, because the rate of increase in car

Table 34

Estimated future rate of return on motorway

Year	Estimated rates of return (per cent)
1960	9·9–15·2
1965	17·6–27·3

traffic is greater than that of commercial traffic, the composition of traffic will probably change. In addition, future benefits may be affected by a wide range of factors, such as technical change in vehicles and in other forms of transport and by more general economic changes such as a falling off in economic and industrial activity. It may be expected, for example, that vehicles will become capable of higher speeds with little or no increase in fuel consumption—in comparing 11 popular makes of car in 1954 with their equivalents in 1957,[19] the mean maximum speed had increased by 7 per cent whereas the fuel consumption per mile (at constant speeds) had fallen by about 4 per cent. Similar factors are probably at work with commercial vehicles, so that the general trend is towards vehicles that are better designed to take advantage of motorway conditions at less real cost.*

On the other hand, it seems likely that railway rates will fall relative to road rates and this will tend to limit the rate of increase in road traffic in the future; there is reason to suppose that the main rail routes parallel to the motorway are the most favourable from the point of view of operation and costs.

Final assessment

In order for the construction of the motorway to be worth-while, it must be shown that the rate of return obtainable is greater than the current rate of interest and (more rigorously) greater than the rates of return obtainable in other uses of capital (including other road improvements).

The relevant rate of interest, indicating the current cost of Government investment, might be taken as the yield obtainable on consols, which stood at about 5 per cent during most of 1958.[20] The rate of return obtainable on the motorway in 1960 (between 10 and 15 per cent) exceeds this rate of interest, and thus fulfils the first condition by a considerable margin, especially as the motorway can be regarded as a virtually riskless investment.

It is more difficult to consider whether the second and more rigorous condition is satisfied because little is clearly known about the rates of return obtainable on capital in a wide variety of different uses. To compare the motorway with returns obtainable on other road improvements, however, with considerable increase in traffic and a low level of road investment until recently, it may be expected that a considerable number of road-improvement schemes would show rates of return considerably higher than the rate of interest.

Thus, included with a selection of nine smaller road-improvement schemes given by Glanville and Smeed[6] and calculated on a roughly comparable but less comprehensive basis, the comparison is less favourable to the motorway, the immediate rate of return from the motorway ranking sixth out of the ten schemes.

In the long term, however, with increasing traffic and its greater reserve of capacity, it would be expected that the comparison with smaller short-term improvements would be more favourable to the motorway.

* So far as reduction in real costs per vehicle are concerned, these would, of course, reduce the value of investment in the motorway in relation to other investments; but they will also encourage more ownership and use of vehicles, which will, no doubt, more than offset this.

SUMMARY

The investigations discussed in this paper were carried out in two parts. The first part was concerned with providing information about the amounts of traffic likely to use the motorway and of its effect on traffic speeds and accidents. The second part was an investigation of the economic aspects of the motorway, making use of information in the first part. The basic traffic data used in the study were obtained in surveys in 1955, but adjustments have been made to give up-to-date estimates of motorway traffic.

Part I—Traffic investigation

The first step in this investigation was to determine the present pattern and speed of journeys by road traffic. This was done in 1955 by carrying out a survey of the origins and destinations of traffic and by measuring journey times on the existing road network. In the origin-and-destination survey, traffic was intercepted at 23 points on roads in the area likely to be affected and 41 000 drivers were interviewed about their journeys. The journey-time measurements, which covered 1800 miles of road, were obtained by test runs with cars, the journey times for goods vehicles being estimated from those of cars. These data were analysed in conjunction with three sets of assumed speeds on the motorway, which were subsequently checked against speed measurements especially made for this purpose on European motorways.

The basic estimates of motorway flows and time savings have been made for 1955, the year in which the traffic studies were carried out. However, separate calculations have been made to determine the effect of subsequent traffic growth on the estimates. On the basis of what would seem to be the most appropriate assumed speeds on the motorway, it is estimated that for the level of traffic obtained on weekdays in June/July, 1955, the motorway would attract 18 500 journeys per day, travelling on the motorway for an average distance of 40 miles out of the maximum of 66 miles; journeys which involved using the motorway for 60 miles or more would constitute only about 30 per cent of all journeys, but, since those journeys would be longer than average, they would contribute just over half of the vehicle-mileage on the motorway. The traffic flow would vary considerably throughout the length of the motorway, the maximum being about 15 000 vehicles per day (both directions combined) near Luton and the overall average being about 11 000 vehicles per day. About 44 per cent of this traffic would consist of medium and heavy goods vehicles, while cars would constitute about 48 per cent, of which more than half would be travelling on business; the remaining 8 per cent of the traffic would be light goods vans and coaches.

Route A.5/A.45, between London and Birmingham, would be the most important contributor of traffic to the motorway and would have its traffic reduced by about 5000 or 6000 vehicles per day; the second most important contributory route would be A.41. Although other routes are individually of minor importance, their total contribution is estimated to be as great as that for routes A.5/A.45 and A.41 combined. The net reduction in traffic on existing roads is estimated at over 700 000 vehicle-miles per day, but the re-routing of journeys would cause flows to rise on roads giving access to the motorway.

The time that would be saved by traffic transferring to the motorway is estimated at about 1·6 million vehicle-hours per annum, and the reduced congestion on existing roads would save a further 0·4 million vehicle-hours per annum. Many of the journeys would increase in distance on transferring to the motorway,

the total annual increase being estimated at 13 million vehicle-miles. On the basis of comparative accident rates on motorways and general-purpose roads in other countries, accident savings to traffic transferring to the motorway are estimated at about 520 casualties per annum, including over 20 fatalities; these savings may be offset by some increase in accident rates per mile travelled for traffic remaining on existing roads. Traffic volumes on London–Birmingham routes are expected to increase by about 30 per cent between 1955 and 1960 (the first year after completion of the motorway) and, on this basis, it is estimated that the motorway traffic flow on weekdays in June/July, 1960, will be about 20 000 vehicles per day on the most heavily trafficked section near Luton with an overall average of about 14 000 vehicles per day. These estimates refer only to traffic transferring from existing roads, but it is expected from experience in the United States of America that extra traffic generated by the motorway itself will increase these estimates by up to 30 per cent.

Part II—Economic assessment

The estimates of traffic flow and time savings resulting from the construction of the motorway were used to estimate the return to be expected from its construction.

Because of the methods of assignment used, and for other reasons, there is a tendency to under-value the benefits from the motorway, but the under-valuation is not believed to be great. The basis of the analysis is the estimate of savings to vehicles, under 1955 conditions and traffic flow, for three different assumptions about speeds of vehicles on the motorway, benefits being valued net of tax and allowing as far as possible for changes in prices between 1955 and 1958.

The report considers first the benefits to traffic assigned to the motorway, estimating the values of savings in persons' working time, in the time of vehicles, in fuel consumption, and in other vehicle-operating costs; the costs of the additional vehicle-mileage incurred in transferring to the motorway is then considered as an offset to these benefits.

The benefits to traffic remaining on existing routes and changes in the cost of accidents are then estimated and finally the rate of return from investment in the motorway is considered.

The capital cost and maintenance costs of the motorway were estimated at £23 300 000 and £200 000 per annum respectively and net annual measured savings arising from the motorway at 1955 traffic volumes gave rates of return on the capital cost of 3·3 per cent, 3·9 per cent and 4·2 per cent for the three sets of assumed speeds respectively. It is estimated that benefits to generated traffic would increase these rates by about 15 per cent.

The effect of unmeasured items, in particular of savings in persons' non-working time, on benefits was then considered and it was calculated that taking a range of values for non-working time would give total rates of return ranging from 5½ to 8½ per cent at 1955 traffic volumes for the first two sets of assumed speeds, which were considered to be the most likely to be achieved.

Finally, the effect of traffic growth on time savings and other benefits was considered and it was estimated that the total rate of return in 1960 would range from 10 to 15 per cent; it was calculated that benefits from the motorway would repay the original capital cost (plus accumulated interest) in 6 to 8 years from that date.

It was concluded, therefore, that one test of whether investment in the motorway was worth-while, i.e. that the rate of return should exceed the rate of interest, had been fulfilled by a considerable margin, although in comparison with immediate rates of return calculated on a few smaller road improvements the immediate rate of return from the motorway was not particularly high.

In the long term, however, it would be expected that the comparison would be more favourable to the motorway.

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APPENDIX 1

LIST OF ORIGIN-DESTINATION SURVEY STATIONS, GIVING LOCATIONS AND TYPES OF ROAD LAYOUT

Station No.	Location	County	Road layout
11	*Road A.1.* 2 miles N. of Baldock . .	Herts	3-lane; lay-by one side
21	*Road A.50.* 1 mile S.E. of Newport Pagnell	Bucks	2-lane; lay-by one side
22	*Road A.50.* 6 miles S.E. of Northampton	Northants	2-lane; lay-by one side
23	*Road A.428.* 2½ miles N.W. of Northampton	Northants	3-lane; lay-bys both sides
31	*Road A.34.* 3 miles S. of Woodstock .	Oxon	Dual-carr.; lay-bys both sides
41	*Road A.41.* 8 miles W. of Aylesbury .	Bucks	2-lane; lay-bys both sides
42	*Road A.41.* 8 miles S. of Warwick .	Warwicks	2-lane; lay-by one side
50	*Road A.45.* 1 mile S.E. of Dunchurch .	Warwicks	Dual-carr.; no lay-bys
52	*Road A.5.* Just N.W. of Markyate .	Herts	3-lane; no lay-bys
53	*Road A.5.* 2½ miles N.W. of Dunstable .	Beds	3-lane; lay-by one side
54	*Road A.5.* 3 miles N.W. of junction with A.50	Beds	3-lane; lay-by one side
55	*Road A.5.* 1½ miles S.E. of Bletchley .	Bucks	3-lane; lay-bys both sides
56	*Road A.5.* 1 mile S.E. of Stony Stratford .	Bucks	3-lane; lay-by one side
57	*Road A.5.* 1½ miles N.W. of Stony Stratford	Northants	3-lane; lay-bys both sides
58	*Road A.5.* 4 miles N.W. of Towcester .	Northants	3-lane; no lay-bys
59	*Road A.45.* Just W. of junction with A.5 at Weedon	Northants	3-lane; no lay-bys
61	*Road A.6.* 2½ miles S. of Luton . .	Herts	3-lane; no lay-bys
62	*Road A.6.* 4 miles N. of Luton . .	Beds	2-lane; lay-bys both sides
71	*Road A.5.* 2 miles N. of junction with A.45 at Weedon	Northants	2-lane; lay-bys both sides
80	*Road A.45.* 7 miles W. of Coventry .	Warwicks	3-lane; lay-by one side
90	*Road A.413.* 8 miles N.W. of Aylesbury.	Bucks	2-lane; no lay-bys
91	*Road A.423.* Southam, 14 miles N. of Banbury	Warwicks	3-lane; no lay-bys
92	*Road A.600.* 6 miles S.E. of Bedford .	Beds	2-lane; lay-by one side

APPENDIX 2

SCHEDULE OF FIELD WORK IN ORIGIN-AND-DESTINATION SURVEY

The duration of the survey was from 6 a.m. to 10 p.m. (16 hours), except where denoted otherwise

The locations of the survey stations are given in Appendix 1

Date (1955)	Reference number of survey station and direction of travel of drivers interviewed					
	Bucks	Oxon	Northants	Beds	Herts	Warwicks
June 20 Mon.	—	—	—	—	—	—
21 Tue.	—	—	—	—	—	—
22 Wed.	—	—	—	—	—	—
23 Thu.	—	—	59 (N.W.)	—	52 (S.W.)	—
24 Fri.	—	—	59 (S.E.)	—	52 (N.E.)	—
27 Mon.	90 (N.W.)	31 (N.W.)	58 (N.W.)	—	—	—
28 Tue.	90 (S.E.)	31 (S.E.)	58 (S.E.)	—	—	—
29 Wed.	—	31 (N.W.)	—	—	11 (S)	—
30 Thu.	55 (S.E.)	31 (S.E.)	22 (S.E.)	—	11 (N)	—
July 1 Fri.	55 (N.W.)	—	22 (N.W.)	—	—	—
4 Mon.	56 (N.W.)	—	71 (S.E.)	62 (S)	11 (S)	—
5 Tue.	56 (S.E.)	—	71 (N.W.)	62 (N)	11 (N)	—
6 Wed.	21 (S.E.)	—	57 (S.E.)	—	61 (S)	—
7 Thu.	21 (N.W.)	—	57 (N.W.)	53 (S.E.)	61 (N)	—
8 Fri.	—	—	—	53 (N.W.)	—	—
11 Mon.	—	—	23 (S.E.)	54 (N.W.)	—	50 (S.E.)
12 Tue.	41 (N.W.)	—	23 (N.W.)	—	—	50 (N.W.)
13 Wed.	41 (S.E.)	—	—	54 (S.E.		—
14 Thu.	—	—	—	—	11* (N)	42 (N.W.)
15 Fri.	—	—	—	—	11* (S)	42 (S.E.)
18 Mon.	—	—	—	—	—	80 (E)
19 Tue.		—	—	92 (S)	—	80 (W)
20 Wed.	56* (N.W.)	—	—	92 (N)	—	—
21 Thu.	56* (S.E.)	—	—	—	—	91 (N)
22 Fri.	—	—	—	—	—	91 (S)

* Night work 10 p.m.–6 a.m.

APPENDIX 3

RECORD-OF-INTERVIEW FORM—PRIVATE CAR OR COACH

PRIVATE CAR OR COACH

(A) Hour commencing (24-hour clock) [|]   (B) Station and Direction Code Number [| |] [ ]

(C) Class of Vehicle (Underline)   1. Private Car   2. Coach   Enter Code No. of Class [ ]

(D) Introductory Remark:—'*Would you mind answering a few questions about the journey you are making? The information is required in connection with the new road programme.*'

(E) '*Where did you start out from on this journey?*'

(i)

'*Have you made any stops since you left there?*'

If NO, omit next question and cancel rectangle (ii).

Private Car: '*Where was the last place that you stopped at for a purpose specially connected with the place? That is, apart from stops for petrol, meals, refreshments and similar purposes.*'

Coach: '*Where was the last place that this coach stopped to pick up or set down passengers?*'

(ii)

Nat. Grid Ref. [| |] [| | |]

(F) '*Where are you travelling to?*'

(i)

'*Will you be making any stops before you get there?*'

If NO, omit next question and cancel rectangle (ii).

Private Car: '*Where is the next place that you intend to stop for a purpose specially connected with the place? That is, apart from stops for petrol, meals, refreshments and similar purposes.*'

Coach: '*Where is the next place that this coach stops to pick up or set down passengers?*'

(ii)

Nat. Grid Ref. [| |] [| | |]

(G) Category of Journey

Enter Code No. [ ]

Private Car: Show the card to the driver and ask:

'*Which of these categories does your journey come under?*'

Enter code no. in box. In case of refusal to reply enter Y.

Coach: Underline one of the following and enter code no. in box.

7. Privately hired or Tour
8. On a regular service
9. Other

[*continued overleaf*

(H) Number of occupants (including driver)	Private Car:		Coach:
Men	Women	Children under 16	Total number of occupants
☐	☐	☐	☐☐

NOTE: Do not make entries in the following sections unless specially instructed

(J) Alternative Routes Enter 1, 2 or 0	☐	(K) Registration Letters	☐☐☐

APPENDIX 4

RECORD-OF-INTERVIEW FORM—GOODS VEHICLE

GOODS VEHICLE

(A) Hour commencing (24-hour clock) [|] **(B) Station and Direction Code Number** [| |] [ ]

(C) Class of vehicle (Underline)

3. Light goods van
4. Lorry or heavy van: 2 axles, no '20' plate
5. ,, ,, ,, 2 axles, with '20' plate
6. ,, ,, ,, 3 or more axles

Enter Code No. of Class [ ]

(D) Introductory Remark:—'*Would you mind answering a few questions about the journey you are making? The information is required in connection with the new road programme.*'

(E) **2 axles (classes 3, 4 and 5)**

'*Where did you start out from on this journey?*'

(i)

'*Where was the last place that you stopped to make a collection or delivery?*'

3 or more axles (class 6)

'*Where was the last place that any load was put on or taken taken off this vehicle?*'

Enter place-name in rectangle (ii)

(ii)

Nat. Grid Ref. [|] [| | |]

(F) **2 axles (classes 3, 4 and 5)**

'*Where are you travelling to?*'

(i)

'*Where is the next place that you stop to make a collection or delivery?*'

3 or more axles (class 6)

'*Where is the next place that any load will be put on or taken off this vehicle?*'

Enter place-name in rectangle (ii)

(ii)

Nat. Grid Ref. [|] [| | |]

(H) Number of occupants (Including driver) Men [ ] Women [ ] Children under 16 [ ]

NOTE: Do not make entries in the following sections unless specially instructed.

(J) Alternative Routes Enter 1, 2 or 0 [ ] **(K) Registration Letters** [| |]

[*continued overleaf*

(L) Unladen Weight
(Not required in the case of Light Goods Van) ☐☐ TONS ☐☐ CWT

Refers to whole vehicle/Excludes one or more trailers. (Underline appropriately)

(M) Total number of axles ☐

(N) Total number of tyres ☐

APPENDIX 5

MAIN FEATURES OF COMMERCIAL-VEHICLE SPEED-LIMIT REGULATIONS IN CERTAIN EUROPEAN COUNTRIES*

Country	Ordinary roads in non-built-up areas		Motorways
	Generally†	Exceptions	
Belgium	37 mile/h	No limit on very light lorries (less than 5 tons maximum authorized weight)	None
		Limit of 19 or 12 mile/h on very heavy lorries (more than 15 tons maximum authorized weight)	
The Netherlands	None	37 mile/h if wheel load exceeds 2½ tons 30 mile/h for lorries with trailers (These cases are thought to affect about 25 per cent of all lorries)	Regulations for ordinary roads appear to apply
Germany‡	37 mile/h	No limit on very light lorries (less than 2½ tons laden weight)	None
France	None	Limits of 37–52 mile/h on very heavy lorries (more than 10 tons maximum authorized weight)	Regulations for ordinary roads appear to apply

* There are no speed restrictions on cars or light goods vans in any of these countries

† i.e. affecting at least 75 per cent of lorries, but usually a greater proportion

‡ These regulations were current at the time of the measurements but were subsequently altered in September, 1957

APPENDIX 6

A FURTHER ANALYSIS OF THE EFFECTS UPON TIME SAVING OF THE COMMERCIAL VEHICLES OF THE THREE ASSUMPTIONS OF SPEED ON THE MOTORWAY

ONE indication that the traffic after the motorway is built will be divided into two fairly distinct blocks—those gaining much by using the motorway and those gaining little (referred to in the Introduction to Part II)—may be given by breaking down Table 24 into components. From this, it appears that by far the most important part of the extra savings over the first set of assumed speeds induced by the second set accrue to vehicles already included in the first; and, similarly, between the second and third set. In other words, the gains in time in the second and third assignments largely reflect existing vehicles getting faster, rather than new vehicles induced on to the road by reductions in journey time. Table A illustrates this.

Table A

Analysis of time savings of Table 24
(000 *hours*)

	Light commercial vehicles	Medium commercial vehicles	Heavy commercial vehicles
Saving on 1st assignment	67	307	209
Saving on 2nd assignment			
Extra savings by vehicles in 1st assignment	31·6	218	311
New vehicle savings	8·4	23	35
Savings given in Table 24	107	548	555
Savings on 3rd assignment			
Savings on 1st assignment	67	307	209
Extra savings by vehicles in 1st assignment	65	383	527·6
Extra savings by vehicles on 2nd assignment	3	25	26·4
New vehicle savings	9	41	67
Savings given in Table 24	144	756	830

APPENDIX 7

WAGE PAYMENTS IN DIFFERENT COMMERCIAL-VEHICLE CLASSES

USABLE data on wages paid per lorry were collected for dates between November, 1953 and mid-1955, for 178 lorries, from four firms. These were in the 3 to 4 ton and upwards capacity-weight category, distributed as shown in Table B with equivalent unladen-weight categories derived from Glover and Miller.[8] As far as could be ascertained, the yearly mileages of the lorries corresponded closely to the data given by Glover and

Table B

Data on wages paid per lorry

Carrying capacity (tons)	3 to 4	5 to 6	7 to 8	11 to 12
Unladen weight (tons)	2 to 2½	2½ to 3	3 to 5	5 and over
Average annual wage	519	569	630*	
Number of lorries	9	68	61	
Average national mileage Glover and Miller (Table 10, weighted by Table 2)(8)	12 000	18 000	20 000	26 000

*Adjusted to exclude mates' wages

Miller. In the 3-ton and over unladen-weight class, the distribution of the 61 lorries by the numbers of axles also corresponds fairly closely to a distribution derived from lorries using A.5 in 1955 as follows:

	A.5, 1955		*More than* 3 *tons unladen weight 61 lorries*	
Two axles	208		29	
Three axles	113	} 204	26	} 32
Four axles	91		6	

£631 was therefore taken as the wage for the more-than-3-ton class. For the 1½- to 3-ton unladen weight class, a figure for the 1½- to 2-ton section had to be extrapolated (this section accounts for less than one-quarter of the total number of lorries between 1½ and 3 tons unladen weight in national figures) at £475. Weighting each section by the appropriate numbers of lorries nationally (Table 232, Annual Abstract of Statistics, 1954), a figure of £530 for 1½ to 3 tons unladen weight emerges. For the under 1½-ton unladen-weight class, no data were available. Since, however, Glover and Miller show that the annual average mileage is 9300 for the under-1-ton class and 9600 for the 1- to 2-ton unladen-weight classes, clearly the elements of extra mileage and overtime affecting wage payments are unlikely to be very much different at this level of weight. Thus the difference in wage *rates* is sufficient guide here; this gives a figure for up to 1½ tons unladen weight at £460.

These final figures, converted to indices, are 100, 115 and 137; there is no reason to suppose differentials have changed much in the 3 or 4 years since the time to which the data refer.

APPENDIX 8

RESULTS OF FUEL CONSUMPTION TESTS

SINCE one of the most important vehicle operating-costs is fuel consumption, tests to simulate the change to motorway conditions were carried out with several vehicles on the 84 miles of A.5 between the junction with A.41 and Lindley, near Nuneaton, and at various steady speeds on the Motor Industry Research Association's test circuit at Lindley. Both A.5 and the test circuit had certain deficiencies in representing present routes and the motorway. For example, not all the traffic expected to transfer to the motorway is at present using the A.5 route; the M.I.R.A. test circuit differs from the proposed motorway in being circular (although with banked bends) and the effect of wind on fuel consumption will be different from that on the motorway, which will run roughly at right angles to prevailing winds. Differences due to this factor have, however, been found to be small. A further defect is that the circuit is virtually flat whereas the motorway is expected to have an average gradient of 43 feet per mile (0·8 per cent or about 1 in 125) with a maximum of 4 per cent. The fuel consumption tests on A.5 show, however, that the ascent and descent of gradients of up to 4 per cent have little net effect on fuel consumption so that this factor may be neglected.

Because of the limited number of vehicles available, it was not possible to test a wide range of vehicles or to attempt to choose vehicles systematically in order to represent the vehicles likely to transfer to the motorway. The six vehicles tested, however, give some indication of likely changes in fuel consumption on transfer to motorway conditions.

Likely changes in fuel consumption will now be considered in detail in three stages:

(i) measuring changes in fuel consumption per mile by test vehicles on transfer to motorway conditions;

(ii) determining classes of vehicle that test vehicles are likely to represent;

(iii) choice of test vehicles representative of these classes, allocation of motorway vehicle-mileage to these classes, and calculation of monetary value of changes in fuel consumption.

(i) Changes in fuel consumption per mile

The main results of the test runs are given in Tables C, D and E and the results are summarized in Table F, the tests being more fully reported elsewhere.* In this table some of the data have been based on a straight-line extrapolation of results; in particular, the speed of 40 mile/h on the M.I.R.A. circuit was unattainable by the medium commercial vehicle and by the heavy commercial vehicle when loaded, and the fuel consumptions for these vehicles at 40 mile/h are therefore estimates.

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* ROTH, G. J. The effect of road conditions on vehicle running costs: a pilot test between London and Nuneaton. *Department of Scientific and Industrial Research. Road Research Laboratory Note* No. RN/3146/GJR. (Unpublished.)

ROTH, G. J. The effect of road conditions on vehicle running costs. Tests of fuel consumption on lorries between London and Nuneaton (A.5). *Department of Scientific and Industrial Research. Road Research Laboratory Note* No. RN/3270/GJR. (Unpublished.)

(These Research Notes are obtainable on application to the Director of Road Research.)

Table C

Fuel consumption tests on trunk road A.5: results for 2·2-litre and 0·80-litre cars

Run No.	Date	Car	Driver	Mean speed (mile/h)			Mean consumption (gal/100 mile)			Consumption on M.I.R.A. circuit (gal/100 mile)		
				London–M.I.R.A.	M.I.R.A.–London	Mean	London–M.I.R.A.	M.I.R.A.–London	Mean	40 mile/h	50 mile/h	60 mile/h
2	Fri. 8/3/57 .	2·2 litre	1	40·6	35·2	37·7	3·75	3·87	3·81	3·21	3·45	3·91
3	Tue. 12/3/57 .	,,	1	36·5	35·2	35·8	3·49	3·66	3·58	2·97	3·20	3·68
4	Wed. 13/3/57 .	,,	2	42·1	36·8	39·3	4·43	4·27	4·35	3·17	3·45	3·87
5	Fri. 15/3/57 .	,,	2	39·6	40·2	39·9	4·57	4·29	4·43	3·06	3·34	3·85
6	Mon. 18/3/57 .	,,	3	38·4	37·9	38·1	3·93	3·85	3·89	3·00	3·30	3·79
7	Tue. 19/3/57 .	,,	3	36·6	37·1	36·9	3·77	3·83	3·80	3·06	3·38	4·06
Mean of 6 runs . . .				38·9	37·0	37·9	3·99	3·96	3·98	3·08	3·35	3·86
8	Thu. 4/4/57 .	0·8 litre	3	35·4	35·5	35·5	2·25	2·27	2·26	1·82	2·28	3·01
9	Fri. 5/4/57 .	,,	3	35·4	34·9	35·2	2·21	2·23	2·22	1·82	2·28	3·01
10	Mon. 8/4/57 .	,,	1	35·4	35·0	35·2	2·23	1·89	2·06	1·96	2·39	3·35
11	Tue. 9/4/57 .	,,	1	34·5	34·0	34·2	2·25	2·02	2·14	1·96	2·39	3·35
12	Thu. 11/4/57 .	,,	2	36·6	35·3	36·0	2·73	2·30	2·52	1·97	2·35	3·11
13	Fri. 12/4/57 .	,,	2	36·3	37·5	36·9	2·55	2·42	2·48	1·97	2·35	3·11
Mean of 6 runs . . .				35·6	35·3	35·5	2·37	2·19	2·28	1·92	2·34	3·16

Table D

Fuel consumption tests on trunk road A.5: results for goods vehicles

Vehicle		Run No.	Fuel used London–M.I.R.A.–London (gal)	Mean speed London–M.I.R.A.–London (mile/h)	Mean fuel consumption (gal/100 mile)	Fuel consumption on M.I.R.A. circuit (gal/100 mile)		
						30 mile/h	35 mile/h	40 mile/h
Medium commercial vehicle (Petrol unladen weight 2·7 tons; laden weight 5·2 tons; carrying capacity 2–3 tons)	loaded	1	14·79	26·6	8·29	8·19	8·75	unattainable
	loaded	2	15·29	27·0	8·46	7·45	7·92	unattainable
	unloaded	3	12·84	29·6	7·11	5·83	6·40	7·08
	unloaded	4	12·61	29·5	6·98	6·25	6·69	7·32
Heavy commercial vehicle 1 (Diesel unladen weight 3·15 tons; laden weight 7·75 tons; carrying capacity 5 tons)	loaded	5	10·10	24·9	5·59	4·81	4·97	unattainable
	loaded	6	11·02	25·1	6·10	5·52	5·62	unattainable
	unloaded	7	8·66	27·7	4·79	4·23	4·58	4·94
	unloaded	8	8·46	28·8	4·68	4·22	4·45	5·15

Table E

Fuel consumption tests on trunk road A.5: results for heavy commercial vehicle 2
(*carrying capacity* 10 *tons, fitted with* (*a*) 350-*cu. in. engine,* (*b*) 375-*cu. in. engine*)

Date	Engine (cu. in.)	Mean speed (mile/h)			Mean fuel consumption (gal/100 mile)			Fuel consumption on M.I.R.A. circuit (gal/100 mile)			Wind speed at M.I.R.A. (mile/h)
		London–M.I.R.A.	M.I.R.A.–London	Overall	London–M.I.R.A.	M.I.R.A.–London	Overall	30 mile/h	35 mile/h	40 mile/h	
15.1.58 . . .	350	27·5	26·9	27·2	7·85	7·38	7·61	4·07	5·39	5·92	2
17.1.58 . . .	350	25·9	28·0	26·9	7·53	6·94	7·23	4·78	5·24	5·82	5
20.1.58 . . .	350	29·7	29·7	29·7	7·66	7·26	7·46	4·66	5·10	5·64	0
Averages for 350-cu. in. engine .		27·7	28·2	27·9	7·68	7·19	7·43	4·84	5·24	5·79	
5.2.58 . . .	375	29·9	28·3	29·1	8·22	7·23	7·73	5·25	5·90	6·65	20
6.2.58 . . .	375	28·8	27·8	28·3	7·98	7·66	7·82	5·25	5·90	6·65	10 (snowing)
11.2.58 . . .	375	28·1	27·2	27·6	7·56	8·25	7·90	5·40	6·00	6·78	40
12.2.58 . . .	375	29·6	29·5	29·5	7·97	4·47	7·72	4·80	5·30	5·96	10
Averages for 375-cu. in. engine .		29·1	28·2	28·6	7·93	7·65	7·79	5·18	5·78	6·51	

Table F

Summary of fuel consumption tests

Test vehicle	London–M.I.R.A.–London		M.I.R.A. circuit		
	Mean journey speed (mile/h)	Mean fuel consumption (gal/mile)	Speed and fuel consumption (gal/mile)		
			40 mile/h	*50 mile/h*	*60 mile/h*
Small car (0·8 litre) 6 runs	35·5	0·0228	0·0192	0·0234	0·0316
Large car (2·2 litre) 6 runs	37·9	0·0398	0·0308	0·0335	0·0386
			30 mile/h	*35 mile/h*	*40 mile/h*
Medium commercial vehicle, petrol (2 runs loaded, 2 runs unloaded)	28·2	0·0771	0·0693	0·0744	0·0803
Heavy commercial vehicle, diesel (2 runs loaded, 2 runs unloaded)	26·7	0·0529	0·0470	0·0488	0·0524
Heavy commercial vehicle (2(a), diesel (3 runs loaded), 350-cu. in. engine	27·9	0·0743	0·0484	0·0524	0·0579
Heavy commercial vehicle 2(b) diesel (4 runs loaded), 375-cu. in. engine	28·6	0·0779	0·0518	0·0578	0·0651

If it is assumed that the test vehicles travel on the motorway at the assumed average speeds for their class, given in Table 23, the percentage changes in fuel consumption per mile due to transfer to the motorway will be as given in Table G for the motorway speeds corresponding to the three assignments, a positive sign denoting an increase and a negative sign denoting a decrease in fuel consumption per mile. In Table G the change in fuel consumption per mile for the medium commercial vehicle at the speed of the third assignment (45 mile/h) has been estimated by extrapolation, the speed being unattainable by the test vehicles.

Table G

Percentage change in fuel consumption per mile due to transfer to motorway conditions

Test vehicle	1st assignment	2nd assignment	3rd assignment
Small car	+ 3	+ 3	+ 3
Large car	− 16	− 16	− 16
Medium commercial vehicle	− 4	+ 4	+ 12
Heavy commercial vehicle 1	− 11	− 8	− 1
Heavy commercial vehicle 2(a)	− 35	− 29	− 22
Heavy commercial vehicle 2(b)	− 34	− 26	− 17

(ii) Classes of vehicle test-vehicles are likely to represent

It is necessary to consider how the fuel consumption data given in Table G may be applied to the vehicle population expected to transfer to the motorway. To do this, it was necessary to consider the more obvious and measurable characteristics of the vehicle population. An indication of the composition of the traffic likely to transfer to

the motorway was obtained by analysing the traffic passing along A.5 at a point about mid-way between London and Birmingham on two weekdays in March, 1958. Private cars and medium and heavy commercial vehicles were analysed separately; the results of the analysis are given in Appendix 9, the sample consisting of 325 private cars and 423 medium and heavy commercial vehicles.

The distribution of cars by engine capacity is given in Table L (Appendix 9), which shows that private cars with engines up to approximately 1·5 litres, whose change in fuel consumption might be represented by that of the small car (0·8 litres), accounted for 62 per cent of the total cars. Private cars with engines of more than 1·5 litres, whose change in fuel consumption might be represented by that of the large car (2·2 litres), accounted for the remaining 38 per cent.

It was decided that the most satisfactory analysis of the characteristics of commercial vehicles would be in terms of carrying capacity and type of fuel used. From data on unladen weight and carrying capacity given by Glover and Miller,[8] a fairly clear dividing line of 6 tons carrying capacity was established between medium and heavy commercial vehicles. Table M (Appendix 9) shows that, of the medium commercial vehicles identified, 55 per cent were powered by petrol and had a mean carrying capacity of 3 tons. The remaining 45 per cent of medium commercial vehicles were diesel-powered with a mean carrying capacity of 4·47 tons; their change in fuel consumption could be represented by that of the first heavy commercial vehicle tested (adjusted to medium commercial-vehicle speeds on the motorway), which had a carrying capacity of 5 tons. Thus 55 per cent of mileage by medium commercial vehicles could be attributed to petrol vehicles, whose changes in fuel consumption could be represented by the medium vehicle tested, and 45 per cent of mileage could be attributed to diesel-powered vehicles represented by the first heavy vehicle tested. The analysis of heavy commercial vehicles is also shown in Table M (Appendix 9) which shows that 88 per cent of these vehicles were diesel-powered, the remaining 12 per cent being powered by petrol. The change in the fuel consumption of the latter, the mean carrying capacity of which was 7·98 tons, could be assumed to be represented by that of the medium commercial vehicle tested (adjusted to heavy-vehicle speeds on the motorway). Diesels of up to 10 tons carrying capacity, with a mean carrying capacity of 7·94 tons, accounting for 50 per cent of heavy commercial vehicles, might be represented by the first heavy commercial vehicle tested of 5 tons carrying capacity. Diesels of over 10 tons capacity with a mean capacity of 15·35 tons, accounting for the remaining 38 per cent of heavy commercial vehicles, may be represented in the change in fuel consumption by the second heavy vehicle tested, which had a capacity of 10 tons.

Thus heavy commercial vehicle-mileage may be divided into three categories, the first accounting for 50 per cent of vehicle-mileage (diesels of up to 10 tons carrying capacity and represented by the first heavy vehicle tested), the second accounting for 38 per cent of vehicle-mileage (diesels of over 10 tons carrying capacity and represented by the second heavy vehicle tested), and the third accounting for 12 per cent of heavy vehicle-mileage (petrol-driven vehicles represented by the medium vehicle tested).

Light commercial vehicles are expected to be relatively unimportant on the motorway, accounting for less than 5 per cent of motorway vehicle-mileage (see Table I), and no testing or analysis of light commercial vehicles was carried out. It is possible, however, to obtain some knowledge of the characteristics of light commercial vehicles from national vehicle registrations.* Table N of Appendix 9 gives the distribution of light commercial-vehicle registrations by unladen weight and by type of fuel used. The mean unladen weight was 0·90 tons (mean carrying capacity approximately 10 cwt) with 99·5 per cent of vehicles powered by petrol. These characteristics conform closely to the small private car tested which had an unladen weight of 0·8 tons. The change in fuel consumption of the small car may therefore be assumed to represent that of light commercial vehicles. The increments in average journey speed of light commercial

* Ministry of Transport and Civil Aviation. Census of vehicles, Quarter ended 30 September, 1956. London, 1957 (H.M. Stationery Office).

vehicles on transfer to motorway conditions are expected to be 9 mile/h, 14 mile/h and 19 mile/h, respectively, for the three assignments; for these increments in speed the change in fuel consumption per mile of the small car (on transfer to the motorway conditions) would be −8 per cent, +2 per cent and +19 per cent for the three assignments.

(iii) Choice of representative vehicles, allocation of motorway vehicle-mileage and monetary value of changes in fuel consumption

Although the test vehicles may be assumed to be representative of the classes of vehicle outlined above, as far as changes in fuel consumption are concerned, they will not necessarily represent the absolute fuel consumption of the classes. It is necessary, therefore, to choose vehicles which represent the above classes in absolute fuel consumption, and the vehicles chosen, together with their fuel costs per mile (net of tax), are given in Table H.

Table H

Size and fuel cost per mile of representative vehicles

Class of vehicle	Mean engine capacity (c.c.) or mean carrying capacity (tons)	Representative vehicle selected	Fuel cost per mile net of tax (pence)
Small car (less than 1510 c.c.)	1280 c.c.	10 h.p.	0·73
Large car (greater than 1510 c.c.)	2510 c.c.	20 h.p.	1·01
Light commercial vehicle (up to 1½ tons unladen weight)	0·5 tons	0·5 tons	0·65
Medium commercial vehicles (1½–3 tons unladen weight):			
Petrol	4·29 tons	4 tons	1·40
Diesel	4·47 tons	4 tons	0·70
Heavy commercial vehicles (over 3 tons unladen weight)			
Small diesels (up to 10 tons carrying capacity)	7·49 tons	7–8 tons	1·11
Large diesels (over 10 tons carrying capacity)	15·35 tons	15 tons	1·45
Petrol-engine vehicles	7·98 tons	7–8 tons	1·88

In Table H representative vehicles and their fuel costs are selected from tables of vehicle operating-costs[(9)] by choosing vehicles conforming to the mean engine capacity of private cars and to the mean carrying capacity of commercial vehicles for the classes given under (ii). Thus cars of up to 1510 c.c. have a mean engine capacity of 1280 c.c. (see Table L in Appendix 9) and a 10-h.p. vehicle is chosen to represent this class; cars of more than 1510 c.c. have a mean engine capacity of 2510 c.c. and a 20-h.p. vehicle is chosen to represent this class.

It remains to allocate the vehicle-mileage transferred from ordinary roads to the motorway among the classes of vehicle given in Table F in order to estimate total fuel cost per annum before transfer to the motorway, and, by applying the percentage changes in fuel consumption given in Table G to the relevant classes of vehicle, the annual change in fuel costs by transfer to the motorway for the three assignments may be estimated.

The vehicle-mileage expected to be transferred from ordinary roads to the motorway is given in Table I for the broad classes of vehicle (excluding coaches, the vehicle-mileage of which is small and may be neglected).

Table I

Annual vehicle-mileage on motorway (000's)

Class of vehicle	1st assignment	2nd assignment	3rd assignment
Private cars	141 820	141 820	141 820
Light commercial vehicles	13 140	14 340	15 270
Medium commercial vehicles	61 281	70 158	75 636
Heavy commercial vehicles	63 448	77 000	82 192
Total	279 689	303 318	314 918

Differentiating between these broad classes and those of Table F and allocating motorway vehicle-mileage to these classes in accordance with (ii) above, the annual vehicle-mileage transferred to the motorway and annual costs before transfer may be estimated as in Table J.

Table J

Annual vehicle-mileage transferred to motorway and annual fuel cost before transfer

Class of vehicle	Annual vehicle-mileage transferred to motorway (000's)			Estimated annual fuel costs before transfer to motorway (£000's)		
	1st assignment	2nd assignment	3rd assignment	1st assignment	2nd assignment	3rd assignment
Small car	87 900	87 900	87 900	267	267	267
Large car	53 900	53 900	53 900	227	227	227
Light commercial vehicles	13 000	14 300	15 300	36	39	41
Medium commercial vehicles						
Petrol	33 700	38 600	41 600	197	225	247
Diesel	27 600	31 600	34 000	75	92	99
Heavy commercial vehicles						
Small diesels	31 700	38 500	41 100	147	178	190
Large diesels	24 100	29 300	31 200	146	177	185
Petrol vehicles	7 600	9 300	9 900	60	73	77
Totals (approx.)	279 600	303 400	314 900	1155	1278	1335

Applying the percentage changes given in Table 29 and in (ii) above, the annual change in fuel costs due to the transfer of vehicle-mileage to the motorway may be estimated. This is done in Table K, a negative sign indicating a decrease and a positive sign indicating an increase in fuel consumption and in fuel costs. Thus it is estimated that the overall saving in fuel costs due to the transfer of vehicle-mileage to the motorway will be £117 000, £84 000 and £18 000 for the three assignments respectively,

equivalent to overall savings in fuel costs of about 10 per cent, 6 per cent and 1 per cent respectively. A discussion of the more important errors and approximations and a comparison with experience on continental motorways are given in the text.

Table K

Changes in fuel consumption and fuel costs

Class of vehicle	Percentage change in fuel consumption			Estimated annual change in fuel costs (£000's)		
	1st assignment	2nd assignment	3rd assignment	1st assignment	2nd assignment	3rd assignment
Small car	+ 3	+ 3	+ 3	+ 8	+ 8	+ 8
Large car	−16	−16	−16	−36	−36	−36
Light commercial vehicles	− 8	+ 2	+19	− 3	+ 1	+ 8
Medium commercial vehicles						
Petrol	− 4	+ 4	+12*	− 8	+ 9	+30*
Diesel	− 8	− 1	+ 6*	− 6	− 1	+ 6*
Heavy commercial vehicles						
Small diesels	−11	− 8	− 1	−16	−14	− 2
Large diesels	−34	−27	−19	−50	−48	−35
Petrol vehicles	−10	− 4	+ 4	− 6	− 3	+ 3
Total annual changes in fuel costs				−117	−84	−18

* Estimated change based on extrapolation of results

APPENDIX 9

CLASSIFICATION OF VEHICLES ON A.5 BY ENGINE CAPACITY OR CARRYING CAPACITY

Table L

Engine capacity of private cars

Engine capacity (c.c.)	Number of vehicles
750 but less than 1000	51
1000 but less than 1250	54
1250 but less than 1510	98
1510 but less than 1750	17
1750 but less than 2000	9
2000 but less than 2250	19
2250 but less than 2500	35
2500 but less than 2750	21
2750 but less than 3000	0
3000 and over	21
	325

Mean engine capacity in the $<$ 1510 c.c. group = 1280 c.c.
Mean engine capacity in the $>$ 1510 c.c. group = 2510 c.c.
Mean engine capacity of all private cars = 1740 c.c.

Table M

Carrying capacity and fuel of medium and heavy commercial vehicles

Carrying capacity (tons)	Numbers of vehicles and fuel used			
	Diesel	Petrol	Unknown	Total
Medium commercial vehicles				
2 but less than 3	5	9	0	14
3 but less than 4	23	25	3	51
4 but less than 5	17	39	2	58
5 but less than 6	29	23	0	52
Totals	74	96	5	175
Mean carrying capacity	4·47 tons	4·29 tons		4·35 tons
Heavy commercial vehicles				
6 but less than 7	40	5	2	47
7 but less than 8	66	12	2	80
8 but less than 10	18	10	0	28
10 but less than 12	19	1	2	22
12 but less than 14	15	0	0	15
14 but less than 16	39	0	0	39
16 but less than 18	4	0	0	4
18 but less than 20	0	0	0	0
20 tons and over	13	0	0	13
Totals	214	28	6	248
Mean carrying capacity	10·74 tons	7·98 tons		10·16 tons

Table N

Light commercial vehicles classified by unladen weight

Unladen weight	Number of vehicles registered in Great Britain		
	Petrol	Diesel	Total
Up to 12 cwt	21 616	21	21 637
12 cwt but less than 16 cwt . . .	156 153	767	156 920
16 cwt but less than 1 ton . . .	266 940	241	267 181
1 ton but less than 1½ tons . . .	118 637	2317	120 954
Totals	563 346	3346	566 692

APPENDIX 10

ESTIMATES OF GENERATED TRAFFIC

It is desired to estimate the additional traffic arising from a reduction in journey time for a sample of journeys between different origins and destinations by means of a relation of the following form:

$$Q = \frac{K}{T^n}$$

where Q = journeys per period between two points

K = a constant expressing the populations and inter-relations between the two points

T = journey time between the two points

n = a positive exponent.

For journeys between two given points, the additional traffic (ΔQ) arising from a reduction of journey time (ΔT) between the two points will be:

$$\Delta Q = Q\left[\left(\frac{T}{T-\Delta T}\right)^n - 1\right] \simeq Q\frac{n\,\Delta T}{T-\Delta T}$$

For a series of journeys between different origins and destinations, the generated traffic in vehicle-miles expressed as a proportion of existing traffic in vehicle-miles will be given by:

$$\frac{\Sigma\, QD\left(\dfrac{n\,\Delta T}{T-\Delta T}\right)}{\Sigma\, QD}$$

where D = distance between origin and destination.

The generated traffic expressed as a proportion of diverted traffic may then be calculated for a sample of journeys which would show time savings and which would therefore be transferred to the motorway. The sample of journeys for which generated traffic is calculated is given in Table O.

The journeys in Table O account for 8830 out of a daily total of 18 500 journeys, and consist mainly of the longer journeys which would use most of the length of the motorway.

Calculating the above expression for the journeys in Table O with a value for the exponent n of 1, gives generated traffic as 10·4 per cent of diverted traffic. A value of $n = 2$ gives generated traffic as 20·8 per cent of diverted traffic, and a value of $n = 3$ gives generated traffic as 31·2 per cent of diverted traffic.

Table O

Sample of journeys used to calculate generated traffic

Journeys between London and S.E. England and following areas and representative towns	Distance (miles)	Journey time and, in brackets, time savings (minutes)				Journeys per 16-hour week-day			
		Private cars	Light commercial vehicles	Medium commercial vehicles	Heavy commercial vehicles	Private cars	Light commercial vehicles	Medium commercial vehicles	Heavy commercial vehicles
Coventry area (Coventry) . . .	90	168 (30)	184 (23)	199 (20)	219 (17)	795	115	290	265
Birmingham area (Birmingham) . .	109	203 (30)	223 (23)	241 (20)	266 (12)	1000	190	845	535
N.E. Midlands (Nottingham) . .	122	236 (33)	257 (28)	277 (27)	303 (25)	135	135	535	475
N.W. Midlands									
(Stafford) . . .	138	260 (31)	280 (23)	310 (20)	340 (16)	380	35	170	260
(Chester) . . .	185	340 (31)	380 (23)	410 (20)	450 (16)				
Lancashire									
(Liverpool) . .	198	350 (31)	286 (23)	420 (20)	467 (16)	835	100	375	450
(Manchester) . .	183	354 (29)	382 (19)	409 (15)	448 (11)				
North Wales (Bangor) . . .	240	450 (31)	490 (23)	530 (20)	590 (16)	70	10	15	15

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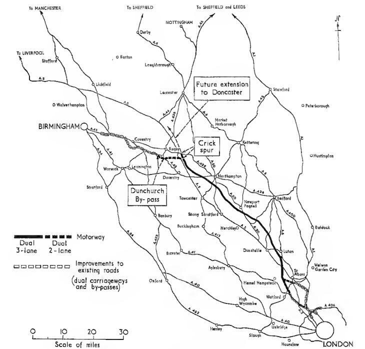

FIG. 1. The London–Birmingham motorway

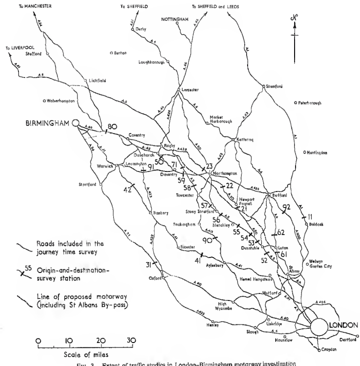

FIG. 3. Extent of traffic studies in London–Birmingham motorway investigation

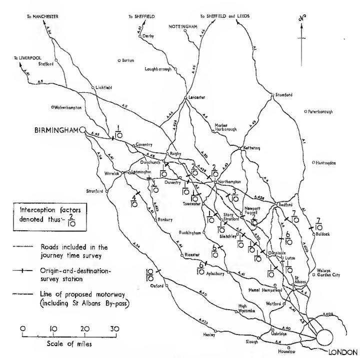

FIG. 8. Interception factors for journeys from London to Birmingham

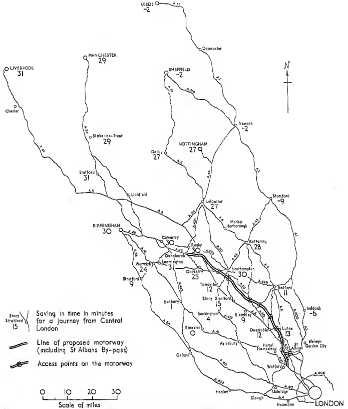

FIG. 9. Estimated time saving for journeys originating in Central London
(*The quickest route is taken for both the present and notional journeys*)

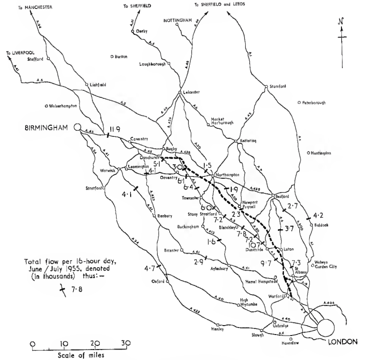

Fig. 14. Observed daily traffic flows at O.D. survey points

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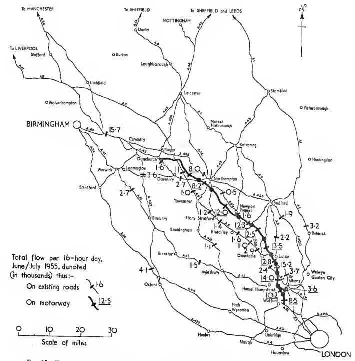

FIG. 15. Expected daily traffic flows at O.D. survey points following transference of traffic to the motorway

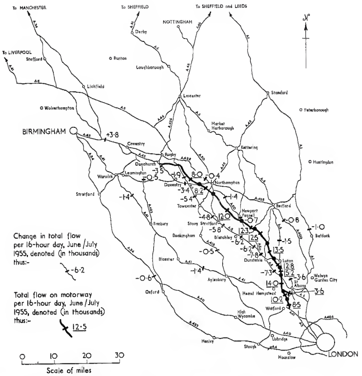

FIG. 16. Expected changes in daily traffic flow at O.D. survey points following transference of traffic to motorway